ON THE

CONSTRUCTION AND PRINCIPLE

OF A

WAVE SCREEN,

DESIGNED FOR THE FORMATION OF HARBOURS OF REFUGE.

BY

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"HARBOURS ARE THE GREAT QUESTION OF THE AGE."

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ADVERTISEMENT.

THE idea described in these pages occurred to the writer when his mind was much engrossed with the wholesale wreckage which occurred upon the north-east coast of England in the gale of the 4th and 5th of January 1857, when it is said 94 vessels and upwards of 150 lives were lost.

Occupied by the demands of public duty, the writer retained the idea floating in his mind without taking any steps towards its elucidation till the present time, when, testing the conception as a means to an end in view of the known character of waves, and of the powers exerted by them, it appeared to recommend itself as correct in principle—as easy of execution—of very general application, and therefore calculated to secure a corresponding benefit. The following pages contain a brief statement of the reasons which led the writer to form this opinion, and it is now presented for the consideration of the reader.

By those who are aware of the necessity which exists for the adoption of means for preventing the loss of life which annually takes place upon our coasts—a loss which has given rise to the well-deserved taunt that "the British coast is the disgrace of the British nation, and the grave of the British seaman," no apology will be needed for this attempt at usefulness, and still less on the part of those who, feeling their responsibility in cases like the present, are ready to take a personal interest in the humane precept "It is better to save life than to destroy it."

ROKER TERRACE, SUNDERLAND, JAN. 1, 1858.

INTRODUCTORY.

The subject is professional, but as the object of the writer is essentially a practical one, and he wishes to insure the conveyance of his meaning into the minds of unprofessional readers, it will be his care not to introduce any technical language where the ideas can be tolerably conveyed by common or unscientific words; it will be equally his object to avoid dogmatic assertion about anything which is strictly matter of opinion; to put before the reader the apparent strength and weakness of opposing views with fairness, and to express himself with clearness and precision.

The occasional reference to another work, and to various reports written and made by the writer is to show, that while the proposal he is prepared to advocate is essentially novel, the laws with which it is supposed to be in harmony have long been a matter of settled belief in his own mind. It is necessary to give a brief description of these laws from the evidence of facts and familiar experience, as far as they are connected with the subject, so as to admit of a judgment being formed respecting the imperfection of the present mode of harbour-building, and also of the possibility of a better system.

The four sections, therefore, into which the subject naturally divides itself, will be adhered to, viz. :—

1.—Waves, and the powers exerted by them.

2.—Breakwaters—long-slope, upright-wall, and floating.

3.—Refuge-harbours, with some of the leading principles of construction and projection, to be kept in view in harbour-designing.

4.—The Wave-Screen, and its effects.

CONSTRUCTION AND PRINCIPLE

OF A

WAVE SCREEN.

SECTION I.

WAVES, AND THE POWERS EXERTED BY THEM.

WAVES IN DEEP WATER—*the Undulation.*—Familiar as most Englishmen are with the appearance of the sea, there are perhaps few subjects respecting which greater misapprehension has prevailed, than the phenomena of waves, and as a right understanding of the nature and power of waves is essential in making designs for harbours and other marine works, a few pages may be usefully devoted to this branch of physical geography, so as to place it in a clear light. Employed afloat, as the writer has been, for the last thirty years, his means of observation have been ample, and what follows upon the point, appears, from his own experience, to be very nearly the fact.

Waves are generally caused by the action of wind over an expanse of water, and consist of risings and fallings, or undulations, which, following each other in succession, give to the surface of the sea an apparently progressive motion. This seeming progress has, however, no real existence in deep water, for, instead of the water advancing with the undulation, the latter alone progresses, while the water remains rising and

falling in the same place. This onward motion of the form, or the undulation, is caused by the latter constantly altering the position of its parts—the water forming the base at one moment, being changed into that of the slope and then the summit at another. Even at the present day the mechanism of waves is but imperfectly understood: the cause of the undulation is said to be "a motion of the particles of water in a circular or eliptical orbit, arising from two forces; the one being that of gravity, and the other the force of the wind, or other motive power causing the wave." Others assign to the particles a vertical movement, which is truly the case for all practical purposes.

Illustrations of what deep-water undulations are, may, however, be readily supplied in a variety of ways. They are represented by the waving movement of the surface of a field of corn in a windy day, where the undulations pass over the field from side to side, while the corn bends and rises again in the same place. They resemble the successive undulations of a rope, which has been subjected to a sharp flip or switch; and lastly—an apt representation may be supplied by putting a round ruler under a cloth, and rolling it across the table; the form of the cloth, as it accomodates itself to the passage of the ruler, representing the undulation, while the cloth itself takes the place of the water. The illustration is homely, but to the point.

The fact of the simple oscillatory character of the deep water wave may be proved by attentively observing the water from a ship at anchor in a calm day, with a swell passing, when it will be seen, that any particles of matter suspended in the water are stationary, as far as horizontal movement is concerned, and if, under such circumstances, a piece of wood or other buoyant substance be dropped into the water, it will not be carried forward, though the waves may be progressing towards the shore at a rate of 12 or 15 miles per hour, whereas,

it is clear, that if the water advanced with the wave, the wood, being in the water, would be borne towards the shore at the same rate. Again: as these undulations often travel extraordinary distances after the forces which have produced them have long ceased to exist, it is no unfrequent occurrence to observe one series of undulations crossing another series of a different size without disturbance, or producing any modification of form or change of direction—instead of this being the case, would not the surface of the sea present the appearance of a sheet of foam, if the water moved with the waves?

By those who regard this character of the wave as a matter of opinion, rather than one of fact, it has been objected that the water must needs be moving with the wave, because a vessel in a calm, and uninfluenced by tide, is carried forward, and that this would be still more the case, were it not that the friction of the water assumed to be passing, is overcome by the inertia of her mass. In reply, it is no doubt true that a vessel under the above circumstances, with her bows pointed in the direction in which the undulations are travelling, will move slowly through the water, and this movement the undulations will impart to her—she will "forge a-head," as it is technically termed, but the reason of this is a very simple one. The front of the wave first reaches the vessel, and as the gravity of her mass becomes active upon the slope thus presented, she moves through the water a distance proportioned to her weight, and the height and length of the undulation; this movement is continued till the summit has passed from under her a little, when, from the reversal of the slope, and the opposite effect of gravity, her way, or movement through the water, ceases. The same operation is repeated with every wave, and the general result is, as observed, an actual progress through the water.

Though the fact of the undulatory character of the wave in deep water has been recognized by men most distinguished in

science from the days of Sir Isaac Newton to the present time, yet, strange as it may appear, a misapprehension upon this point, gave rise to the expression of many conflicting opinions before the Harbour of Refuge Commission in 1844.

Their height, shape, and rate.—The height of waves, or the perpendicular contained between the level of the summit of an undulation and the level of the antecedent hollow, is also a point upon which there is great difference of opinion. This is not to be wondered at, for there is much that is illusory in the appearance of an advancing wave. Endeavour, as one approaches, to estimate its height, and then notice what it really is as the wave passes a gauge or other upright object, and in the great majority of cases, not half the supposed height will be indicated; the eye, in short, is deceived by the mass of the wave, and conveys a false impression of its magnitude. It is very difficult to determine the height of deep-sea waves with accuracy, on account of the rapidly-varying motion of the vessel, from which the observations must necessarily be made —movements, which it requires considerable practice to make the proper allowance for, and after all, the results thus obtained, even by the most experienced seamen, can only be regarded as approximations to the truth.

A few estimated heights may be given. The late Doctor Scoresby stated in a communication to the British Association in 1850, that during several hard gales in the Atlantic, he had measured many waves of about 30 feet, but the highest was 43 feet from the hollow to the crest. Another authority assigns 45 feet as the height of Atlantic waves measured at the island of Ascension, and declares that at times they attain an elevation of 60 or 70 feet in the neighbouring open sea. On the other hand, a gentleman of ingenuity and observation, in giving evidence before the Select Committee on Shipwrecks in 1843, said, "I have measured the height of waves in the

Atlantic in a heavy gale, and I have found none to exceed 19 feet in height from the trough of the sea to the highest point,"—and upon its being remarked, that perhaps the vessel was not upright, and his measurement was faulty, rejoined, "Of course I made allowances, but after repeated trials, I have found none to exceed 19 feet."

With such discordant testimony before us, the maximum height of ocean waves must still be regarded as undetermined, but whatever may be the case in the wide and deep Atlantic, we are certain that waves of great magnitude can neither form in our narrow seas, nor reach our shallow shores. Upon this point, which is one of so much practical importance, we have some interesting and conclusive evidence furnished by the Messrs. Stevenson, Civil Engineers, of Edinburgh, and the builders and designers of the lighthouses, and a great proportion of the artificial harbours of Scotland—Mr. Thomas Stevenson, in the article "Harbours" in the *Encyclopædia Britannica*, remarks, "At the mouth of a harbour on the German Ocean, with a fetch (or expanse in front) of 600 miles, the writer had observed for him the height of waves during south-easterly gales, and on one occasion the result was 13½ feet from the crest of the wave to the trough of the sea. In deep water, and with a north-easterly gale, there is no doubt that the waves of the German Ocean will attain a height considerably greater than this." The foregoing example supplied by the Messrs. Stevenson, agrees with one by the Comte de Marsilli, quoted in the same article, viz., "that the highest wave on the shores of Languedoc, in the Mediterranean, where the breadth is 600 miles, was 14 feet 10 inches." In estimating, therefore, from the above examples, the probable height of a deep-water wave on the eastern coast of England, where the breadth of the sea in front is about 300 miles, or half that quoted above, we may safely assume that 15 feet for the maximum height of a wave, will be rather over the mark than under it.

As regards shape, the length of the wave in the direction of motion, or the distance from hollow to hollow, has no fixed relation to the height. The water continues to undulate long after the wind which produced the waves has ceased, and they advance with an undiminished length, while their height gradually decreases under the influence of gravity or other resistance. It may be stated as a general fact, that half-spent waves are long and low, while the active wave during a gale, appears from the difference in its proportions, comparatively short and high.

As waves are of unequal magnitudes, so do they move with unequal velocities. The rate at which the deep-water undulation travels has been assumed to depend upon the depth of water, but this can scarcely be the case, as waves of different sizes are often observed passing over the same spot with different degrees of speed. Even large waves do not attain to any considerable rate, for it is no unusual circumstance for a vessel going 12 or 14 miles an hour through the water, to keep nearly "neck and neck" with them, and though the undulations eventually pass her, they do so but slowly. The writer has several times noticed by measurement, that a 6-feet wave moves at the rate of about 12 miles an hour, and it is probable that a 15-feet wave seldom exceeds the rate of 15 miles an hour.

Depth to which their influence is felt.—In Typhoons, and other violent tempests of tropical regions, where waves of great height are generated, the influence of the wave has been known to extend to a great depth, but as there are no such billows on our shores, similar effects cannot be looked for. That waves occasion a disturbance at a depth of at least 15 fathoms upon our eastern coast, is apparent, from water of that depth being often charged during gales of wind with the detritus, or matter comprising the bottom; and the writer has

often observed waves of 6 or 8 feet change water with a depth of 7 or 8 fathoms. The late Professor Edward Forbes mentioned, that the *Venus Cassina,* a large shell not known to live at less depth than 7 fathoms, is often thrown up during heavy gales on the coasts of Scotland, Ireland, and the Isle of Man. Mr. Wilson, the Harbour Master at Holy Island on the coast of Northumberland, informed the writer, that the Pegasus steamer, which sank in 11 fathoms a little to the northward of the Goldstone, lay there till the occurrence of a heavy gale from the north-eastward, when she broke up at high water, and part of her wreck was driven ashore. Mr. Coode, the resident engineer for the construction of Portland breakwater, in his under-water examinations of Chesil Bank, obtained a clear proof of the influence of the wave at a depth of 8 fathoms; and during the survey of the North Sea, conducted by Captain Washington, the present Hydrographer of the Navy, it was noticed that the sea had the power of moving shingle towards the main at even a greater depth.*

That this action of the wave, whatever it be, is not a very decided one, is obvious. The Astronomer Royal stated in evidence in 1845, that "the motion of waves diminished in descending with a degree of rapidity which nobody would imagine at first. Suppose," he says, "a wave 10 feet long from ridge to ridge (and the same applies to every one, except one of very great length, like a tidal wave), if you descend 10 feet below the surface, the disturbance of the water is less than $\frac{1}{500}$ part of what it is on the surface, and if you descend 10 feet below that, it is diminished 500 times again—the reduction goes on in geometrical progression." Major-General Pasly, in writing to Sir Byam Martin on December 1, 1845, stated that "it was found by the divers employed in removing the wreck of the Royal George at Spithead, that the action

* For some other facts showing the action of waves, see Calver's Treatise on Tidal Rivers, pp. 86 and 87.

of the waves was nearly entirely superficial—that they could work as effectively in the heaviest sea as in a calm, and that they were often most successful in strong gales of wind."

We have yet to learn the nature of the sub-action of the deep-water wave. In the instance of the Chesil Bank, just alluded to, the movement seemed due to the undertow, or drawback as it is termed, of the surface wave, whereas, in the case of the shingle travelling towards the main, the movement was the effect of a propelling power, as it were; but whatever the power may be, it does not appear to be in any way allied to percussive, for it is stated by Mr. Coode after 10 years experience, that the action of the waves upon Portland breakwater clearly proves, that even a powerful breaker has no percussive action below a depth of 12 or 15 feet from the surface of the water.

Their broken crests.—From the oblique action of the wind upon the water, a general drift is given to the surface particles during gales; the friction of the wind sharpens the undulation. and has, as it were, a tendency to blow the summit of it over, Thus, every deep-water wave in storms is more or less crested, and the summit (breaker-like) doubles over, and runs as foam down the front incline of the undulation. The velocity of this broken or dead water, bears but a small proportion to the velocity of the undulation upon which it is formed, for every seaman will have observed, that a broken crest ocurring a-stern of his vessel when she is making good way, is quickly distanced and left behind, whereas the undulation will overtake and pass the ship.

The same feature may often be observed even in a calm day, if the undulations happen to be advancing against an opposing current.

An undue importance is often given to these broken crests, and they are confounded in volume and effect with the

massive and powerful breaker on the shore. This exaggerated idea of the power of the former, has probably arisen from not properly estimating the weakness of the objects demolished by them: they will, no doubt, when seconded by the plunging, or other movement of a vessel, make havoc with her bulwarks, and sweep away her boats, the former being a comparatively feeble structure, and the latter light bodies with a large surface, possessing no inertia to resist the stroke of the spray. The fact is, the crest of the deep-water wave, being broken into foam, and its strength diffused, has in reality very little of a "ram-like" power: what effect, for example, has it upon the sharp bow of a steamer or other vessel advancing against it? —what against the Dutch fishing vessels, which ride at their anchors in all weathers, a service which was also performed by the Tender employed in the North Sea Survey, without the slightest accident or damage? It follows, therefore, that the crest of a deep-water wave would be harmless in the case of a structure properly designed to resist it.

It is highly interesting to know, from its direct bearing upon harbour construction, that a very slight obstacle is sufficient to reduce the size of this miniature breaker, and even to destroy it. Admiral Bullock says he has often observed fishermen's nets cut off the crest of a deep-water wave, and produce comparatively smooth water under their lee. Many boats driven off shore by gales of wind, have been saved with their crews by riding under the lee of their spars formed into a raft, over which the surface drift or crest has fallen and expended itself, thereby placing the boat in a smooth. Major Parlby, in his evidence before the Select Committee on Shipwrecks in 1843, alluded to the effects on the surface breaker of ocean waves at the Cape of Good Hope, produced by the seaweed *Laminaria buxinalis*, which grows in a tubular form in lengths of 20 or 30 feet or more—the upper end is trumpet-shaped, and floats on the surface, while the lower end

is attached to rocks at the bottom. But one of the most marked effects is produced by oil. It is well known that fishermen have long been in the practice of towing a mass of greasy garbage astern of their boats to cut off and destroy a following sea. Dr. Franklin suggested "the pouring of oil on the sea to still the waves in a storm," and before his time, Martin wrote an account of the "Western Islands of Scotland," wherein he says, "The steward of Kilda, who lives in Pabbay, is accustomed in time of a storm to tie a bundle of puddings made of the fat of sea-fowl to the end of his cable, and lets it fall into the sea behind the rudder. This," he says, "hinders the waves from breaking, and calms the sea." The foundering of the screw-steamer William Beckett of Goole, off the Scaw, on the 12th of November, 1856, is another case in point, for the escape of her crew in the boats, through a heavy sea, was solely due to the use of oil. Dutch fishermen often resort to the same means when running in their vessels before a heavy sea, and a gentleman at Scarborough mentioned to the writer, that he had often seen them do it in entering the harbour there in heavy weather, and that the effect produced upon the water by the diffusion of the oil was quite magical; the following crests were completely cut off, and a broad and smooth wake established behind the vessel. No doubt the same process might be made use of to insure the safe beaching of life-boats. The above interesting facts are of great practical importance, for they show that the wave-crests may be readily reduced by apparently trifling means.

It is also necessary to observe before passing on, that as this feature is caused by the wind, it requires space before it can gain fresh volume, when it has once been broken and destroyed; it requires time, in fact, before the wind can form the miniature wave afresh. Look, for example, at the sea in an off-shore gale—the water near the shore will be observed to be blue and unbroken, and a surface-breaker or crest is not formed upon

the increasing undulations until they have gained an offing of several miles. It may therefore be accepted as fact, that when once broken, no surface-drift, of any practical importance, could form in the limited space afforded by a refuge harbour.

Modifications of their movement.—The deep-water undulation is operated upon by a variety of causes, and it may thereby be intercepted—reversed—reduced—retarded—re-directed, and destroyed, the qualifying elements being the tides, or the friction arising from the bottom or from the margin of the sea.

Every seaman has observed the effect of a tide-way in "running-down" a sea, as it is termed; during the strength of the stream, the breakers upon the shore within are comparatively small, but directly the stream ceases, the undulations are "let loose," and reach and burst upon the strand with their original force. Mr. T. Stevenson gives a striking instance of this fact—he says, "that from observations specially made at Sumburgh-head lighthouse, in Shetland, during a westerly storm, so long as Sumburgh Roost (one of the most formidable tide-ways in those seas) was cresting and breaking heavily, one could easily have landed in a small boat at a creek or bay called the West Voe; but, no sooner did the Roost disappear towards high water, than there came in towering billows that totally submerged cliffs of very considerable height."

The undulations may be reversed and reduced. When they advance from deep water upon a rocky and steep line of coast, each undulation on reaching the face of the cliff or other obstruction, becomes piled or heaped up, and then falling by the force of gravity, assumes the form of another wave, which, retiring seaward in a direction opposite to that of the initial wave, opposes, and materially reduces in height that arriving next in succession. The useful lesson to be learnt from this is,

that a deep-water undulation, before it can reach an upright barrier, must have become reduced in height—in fact, partially destroyed, and from the numerous instances of recoil observed by the writer, he has no reason to suppose such reduction to amount to less than one-third of the initial height of the wave.

The undulation, from being susceptible of friction also, is influenced by the depth of water and the form of the shore upon which it is advancing. As the waves arrive in shoaler water, and feel the effect of the bottom, they become lower and shorter—their crests are more broken, and the bottom has consequently the effect of partially "tripping them up," as it were. Should the waves in their advance be cut off between the horns of a bay, then the effect of friction is still more apparent in the bent form of the undulations, and which will continually increase till they become packed in narrow and deeply-bent ridges at the head of the bay. Friction also produces a well-marked effect upon waves advancing from deep-water obliquely to the general line of shore—as they receive the impression of the ground, they pivot on their near-ends, and, gradually taking the form of the shore, advance nearly directly upon it.

Lastly, the deep-water undulation, or a portion of an undulation, is quickly destroyed by an expanse. When, for instance, its continuity has been broken by the interception of an artificial work, and the detached portion arrives at an expanse, it quickly subsides, and becomes lost. An instructive instance of the sort is afforded by Sunderland Harbour, where the heaviest seas fall, in height, directly they arrive at the beaching ground, or stilling basin, an expanse about 800 feet within the pier-heads, and they become altogether subdued in a further distance of 200 or 300 feet.

The foregoing characteristics of the deep-water wave, which will have been noticed by any one of common observation, are principles which must be recognized in designing harbours correctly.

WAVE IN SHALLOW WATER—*the Breaker.*—In shoal water, the wave is no longer a simple undulation: it then becomes a wave of translation; that is, the water forming it acquires progressive motion, which motion eventually imparts to the breaker percussive force. As the depth decreases and friction increases, the wave becomes shorter—its front-incline becomes steeper than the rear-incline, and more and more approaching a perpendicular, until at length the crest, which is being impelled forward at a greater rate than the foot, overhangs, and then falls with tremendous force upon the shore, or other object opposing its advance. It matters not whether the friction which causes the breaker be that of the bottom, or of an artificial work presenting the same profile.

The undulations during gales on our eastern coast, are seen to assume a different character in a depth of about 5 fathoms —that is, they are more crested than those of deeper water, but there is no breaker, properly so called, until they arrive in shoaler water, the point of breaking appearing to depend principally upon the relation between the height of the wave, and the depth of water in which it moves. In the report of the experiments on waves made for the British Association by Mr. Scott Russell, it is stated that, "A wave breaks when its height above the antecedent hollow is equal to the depth of water," the meaning of this is, it is presumed, that a 15-feet wave breaks in 15-feet water, which accords very nearly with common observation. Mr. T. Stevenson remarks, in the article on Harbours already alluded to, "We have repeatedly seen at different parts of the coast breaking waves of from 4 to 5 feet, measured from hollow to crest, in from 7 feet 8 inches to 10 and 11 feet of water, measuring from the bottom up to the mean level, and on one occasion we were told of waves which were estimated at 9½ feet in 13 feet of water."

The breaker being a weighty body of water, falling over and thrown forward with a velocity little less than the wave

had as an undulation, naturally acts with enormous force, its momentum, like that of a solid, being the weight multiplied by the velocity. The vessel which meets and opposes the deep-water crests unharmed, is quickly battered and shivered to pieces by the breaker, the percussive force of which it is well known, will at times level rocks, as well as sweep away artificial works opposed to their course.

Some of the recorded instances of the power of breakers, are interesting and instructive.—Mr. T. Stevenson narrates, "he has seen at Port Sonachan in Loch Awe, where the fetch is under 14 miles, a stone weighing a quarter of a ton torn out of the masonry of the landing-slip and overturned,"—that "in November, 1817, the waves of the German Ocean overturned just after it had been finished, a column of free-stone 36 feet high and 17 feet base; the diameter at the place of fracture was about 11 feet,"—that "in a gale at Granton in December, 1836, one stone was moved measuring 15 cubic feet, or about one ton in weight, and thrown on the beach, after having been built into the wall,"—and that "he knows from the testimony of an eye-witness, of a block of 50 tons weight being moved by the sea at Barra-head, one of the Hebrides,"—and, what is more extraordinary than all, "that blocks of 6 tons weight have been quarried, or broken out of their beds *in situ*, on the top of the Bound Skerry of Whalsey in Zetland, which is elevated 70 feet above the level of high water spring tides." No one who is acquainted with the appearance of the sea in storms in the latitudes referred to, and has observed the breakers dashing against the cliffs, and throwing their spray several hundred feet up the neighbouring heights, will be at all surprised at the foregoing examples of their percussive force. Mr. Stuart, the superintendent of Plymouth breakwater, also states, that so enormous is the force of the breakers upon one part of that work, "that stones of 10, and even of 15 tons weight, have been taken from below

low water, and carried over the top of the breakwater." The history of the breakwater of Cherbourg, and of other works of similar design, all bear like testimony to the destructive power of breakers.

It has been attempted to subject their percussive force to measurement, and for this purpose an instrument named the Marine Dynamometer has been invented by the Messrs. Stevensons. By means of this instrument, Mr. Stevenson "found the force of the waves of the German Ocean during hard gales to be 1½ ton per superficial foot at the Bell Rock, and of the Atlantic Ocean to be 3 tons per superficial foot at the Skerryvore Lighthouse. These experiments were of course made upon actual breakers, for the undulating character of a deep-water wave would be altered directly it felt the influence of the sub-mass of the rocks where the observations were taken, and become converted into a breaker; the results registered no doubt convey a correct idea of their power.

These examples are interesting, but if it were attempted to deduce from such observations a law, without taking into consideration the modifying circumstances of locality, it would afford another proof that "there is always danger in generalizing from particular cases." At Sunderland, for instance, where the coast is exposed to the whole fetch of the German Ocean, and where we have assumed the existence at times of a 15-feet wave, or one as high as those recorded from actual observation at another position on the same ocean, the North and South Beacons (marking the rocks on either side of the harbour), formed of wood, without stay or support, resist successfully the breakers of the heaviest gales, which assuredly would not be the case, if a tithe of the force recorded at the Bell Rock was acting upon them. Sir Samuel Brown stated that at Brighton he found the impetus of waves (breakers) during heavy gales, "equal to 80 lbs. to a foot upon a cylindrical column of 12 inches diameter," which appears to agree

more nearly with the force to which the Sunderland beacons are subjected, and withstand. The stability of these objects is no doubt in part due to their cylindrical form, but other conditions must obtain in the localities in question to account for the comparatively small amount of force displayed. Smeaton termed breakers "those powers of nature that are subject to no calculation," from his sense of the difficulty of determining their force, and it is evidently one of those cases where it is necessary to make a wide induction of a number of individual examples, to insure arriving at a correct result.

It appears unnecessary in a work like the present to notice the theory of a *Flot du fond*, a sub-marine or ground wave, said to be present in deep water during storms, and to proceed from thence into shallow water, the more especially as Professor Airy considers such theories to possess very little value.

To recapitulate—we have seen respecting the

Wave in deep water,

That it is an undulation, possessing no horizontal percussive force.

That its height, shape, and rate, depend upon the modifying influence of locality.

That its effect at some depth below the surface appears to partake more of the character of a disturbance than of a direct force.

That its broken crest resembles the breaker only in form—that it has small comparative power, and that it is easily resisted and subdued.

And that the undulation, by the influence of local causes, may be intercepted, reversed, reduced, re-directed, and destroyed.

We have also seen respecting the—

Wave in shallow water,

That it is a breaker, or wave of translation, possessing percussive power, and producing an effect proportioned to its own mass,—to the rapidity of its movement,—and to the nature of the obstacles opposed to it.

SECTION II.

BREAKWATERS.

BREAKWATERS for intercepting the force of the waves, and forming a sheltered haven, or roadstead, wherein vessels may lie in safety in all weathers, are of varied construction: there are, however, three principal kinds, viz., the Long-slope—Upright-wall and Floating, which it is proposed to consider.

LONG-SLOPE.—*Nature.*—There are many well-known modern examples of this description of breakwater, as at Cherbourg, Plymouth, Kingston, Howth, &c., and it was adopted by the ancients at a very early period, especially by the Greeks at Tyre and Carthage, and by the Romans at Athens and Halicarnassus—the same design was also followed at a later period at Venice, Genoa, Rochelle, Barcelona, and at many other places.

Long-slope breakwaters are formed by throwing down stone-rubble, as it is obtained from the quarry, on the projected line for affording the desired shelter, till the material reaches to above high-water springs—as a necessary consequence, therefore, the bank of stones thus deposited will have sloping sides; the stroke of the wave is then allowed to act upon the mass until it has assumed that form which is best suited to resist the wave action, the inclination which the outer side thus acquires being termed the angle of repose; after which, the work from low-water mark upwards, is faced on either side with rubble, or squared masonry set in cement.

Slope.—The size of the long-slope breakwater will depend

upon the depth of water in which it is placed, and the area to be sheltered, while the angle of repose of the outer slope will be the measure of the exposure, and the consequent weight of the sea acting upon the work: hence, the profile varies with the locality, thus—

Cherbourg breakwater, in its outer face, has four distinct slopes from the summit downwards. The upper line of talus, which is only acted upon by the higher break of the wave, has a height proportioned to its base of 100 to 185—the second stage, being between the levels of high and low water of equinoctial tides, and thus constantly exposed to the whole of the battering power of the breakers, is the most inclined, viz., as 100 to 540—the third stage, being between equinoctial low-water and that point below the surface where the action of the breaker ceases to be felt, is as 100 to 302, and the fourth, or lowermost stage, which is beneath the action of the waves, has a slope of 100 to 125. The upper slopes of this work are now being removed, on account of the failure of the principle, and the necessary alteration in the design of the work.

Plymouth breakwater appears, from the account of Sir John Rennie, to have a slope of 2½ or 3 to 1 from the bottom to 8 feet below the level of low-water springs—of 3 or 4 to 1 from thence up to low-water springs, and after that of 5 to 1 to high-water springs.

Portland breakwater, according to Mr. Coode, has a slope of 1 to 1¼ from the bottom up to the depth of 12 feet below low-water—then of 1 to 5 to low-water, and lastly, of 1 to 6 or 8 between the levels of high and low water.

The inner slopes of these several works, not being exposed to wave action, remain as they were deposited, generally at a slope of 1 to 1, or an angle of 45°.

There are many other long-slope breakwaters, both in this and in foreign countries, but the foregoing examples are sufficient to convey an idea of the nature and form of such works.

Defective principle.—Reverting to what was stated in last section, that a wave becomes converted from an undulation into a breaker by the obstruction of a shallow foreshore, or anything presenting the same profile, the defective principle of the long-slope breakwater will be at once apparent. Supposing the work to have been formed in a depth of 5 or 6 fathoms, it will be evident, that the deep-water wave which previously undulated harmlessly, because without percussive force, will become, by the establishment of the sloping breakwater, a powerful and destructive agent—the interposition of the work compels the wave to break, and the whole mass rushes up the slope with the velocity with which the wave itself moved, and by the constant action thus going on, every wave makes some change. We have seen what the force of breakers is, and it will be evident, that if the hardest rocks are unable to withstand their sustained action, masonry must be still more powerless, however it may be arranged, set, or compacted: hence, it has not been unusual for the sea to cause damage in a few hours to an amount which has required months of labour and a large outlay of money to repair. The destructive batter of the breaker is, in short, a constant protest against the principle of a work, which thus, "Faust-like," calls up a spirit from the vasty deep, for its own destruction.

To test the principle more closely, and to see what the slope involves:

The long-slope breakwater is defective in principle, because the first burst, or plunging stroke of a breaker, is upon the weakest part of the work, viz., its foot or toe, where, the stones being placed promiscuously, and unconnected, there is no mass to resist the momentum of the breaker. The result is, that the digging stroke displaces the stones, and then hurls them over the top of the work, an operation materially facilitated by the paved surface of the upper slope.

It is defective in principle where it is open to the action of

an oblique sea, for every wave so acting, has a tendency to move a portion of the material, as in the case of a beach, and when the masses so moved have been carried to the end of the breakwater, the next wave casts them clear of it. The effect of the preponderating oblique sea, consequently, becomes in the end apparent as a mass of rubbish in the form of a reef or shoal projecting from the end of the breakwater into the harbour, an effect only to be prevented by a large annual outlay. This has been the case especially at Cherbourg—Donaghadee—Portrush, and Dunmore, &c.: it was admitted by one of the strongest advocates for sloping breakwaters that it would have been the case at Dover also, had such a work been attempted there.

It is defective in principle, because it is exposed not only to the direct action of the wave, but also to its recoil, which is almost as injurious—tending, as it does, to undermine the lower portions of the work.

It is defective in principle from the want of solidity, arising from the presence of vacuities. In Plymouth breakwater, for instance, only the largest stones were used, and the result, as stated by the late Mr. Rendel, was "that 32 out of every 100 feet mass were vacuities," the air contained in which, when subjected to the percussion of a breaker, is as explosive as gunpowder, and sufficient to wreck any work. In later structures of a similar description, this evil has been partly avoided by the employment of material of all sizes, but as the sea will work out the smaller particles within a certain distance of the surface, the same defect will always exist in a degree.

It is also defective in principle because such a work, though finished and apparently secure, can never be really safe. The occurrence of a heavier gale than that which caused the last disposition of the materials, especially if it acts from a different direction, must subject the work to injury and wreckage.

Mr. G. Rennie, in remarking upon the breakwater at Plymouth, said "If nature has not a stronger storm than it has hitherto had, it will remain firm, but if a stronger storm comes, it (the breakwater) will alter again."

Cases of Wreckage.—Where a mistake of this sort has been made, no permanency can be looked for, as the destructive agents are always at work exacting the penalty for the blunder. Nature, in these cases faithful to the laws which are enjoined, but which we choose to neglect, vindicates herself, and shows her independence of our plans, by thwarting all our views, and rendering useless all our efforts. The history of long-slope breakwaters, without exception, presents a series of disasters. To instance a few cases:

Cherbourg breakwater, Capt. Washington reports, was three times raised above high-water between the years 1790 and 1832, and as often beaten down again by the waves. It also appears, that after every effort that skill or experience could suggest to give it stability, the long-slope mode of construction above low water was abandoned, and an upright wall has been adopted as the only alternative.

Plymouth breakwater, Mr. Stuart relates, has several times been partially wrecked. In the night of the 19th January, 1817, the upper and finished part of the work was demolished, and the stones thrown over the north, or inner slope. On the night of the 22nd November, 1824, and the morning of the 23rd, 796 out of 1241 yards, roughly finished, were overturned in a few hours; and so late as 1838, a great quantity of stones were dislodged from the foot of the slope at the west end, and thrown over on the north side; among them were blocks of 15 tons weight, as before mentioned. In 1844, the work had been 32 years in hand, and was still unfinished, and during that period, scarcely a winter had passed in which some part of the breakwater had not been damaged. Captain Vetch

visited it in 1845, and he stated in evidence, "that he has seen seas break completely over it, even at low water—that all attempts to construct a breast-wall at the top of the sea-slope failed, and that immense blocks of stone secured with iron bolts and straps were carried away, and no attempts dare now be made to repeat these experiments. He also remarked, "it is by no means a complete work, and it would still require a long period, and a great cost of public money to make it so."

Howth breakwater sustained great damage in a N.E. gale on the 4th January, 1809, when a length of 80 yards out of 300 was destroyed.

"Kingston (quoting from the report of the Refuge Harbour Commissioners in January 1846) has required constant and heavy repairs, and is still unfinished." General Sir Harry Jones, in his letter to the Commissioners on June 1st, 1844, remarks, "Kingston still remains as insecure as heretofore: the enormous mass of stone placed on the outward slope at the line of low water is greatly acted upon with almost every easterly gale, and certain portions of the loading are washed away: even with the long-slope which this pier possesses, the waves in very heavy gales of wind run over the apex, and falling down, have repeatedly disturbed the surface of the roadway in the inner side."

"Ardglass pier [still quoting from the report of the Commissioners], built in 1829 of large rubble stone with a long slope, now lies, together with its lighthouse, a mass of ruins in the sea."

"Donaghadee pier, constructed in 1820 of rubble stone, with a long sea-slope, has had its glacis torn up by south-easterly gales, and a part of the materials carried half-way across the harbour's mouth."

"Portrush pier, constructed in 1826 of large rubble stone, with a long slope, was found to be so much damaged in 1844, that the engineer called upon to examine it reported that

4000 tons of material had been washed from the outer extremity of the slope round the pier-head, and had formed an artificial reef 70 feet in length, rising 3 feet above low water."

"At Dunmore, the pier was built in 1815 of large rubble stone: in 1832, the works were in so ruinous a state, that the engineer reported that the sea pavement had been broken up, and the pier breached through almost its whole length, and that the breaches were widening and advancing towards the pier-head every storm. When examined in 1845, it was found that many large stones had been previously washed from the slope, and then formed a spit from the pier-head 112 feet long, projecting in a slanting direction across the harbour's mouth, and dry at low water."

The history also of the havoc annually made on the mole of Algiers during two centuries, is merely a recital of disasters similar to those already detailed.

Arguments used in their favour.—Notwithstanding all this unvarying experience of its weakness, the long-slope breakwater is not without its supporters.

It is urged in favour of the long-slope, that nature gives the same form to a beach &c.; this is certainly true, so far as general form is concerned, but here the comparison ends. The beach is constantly undergoing a process of change, the loose materials of which it is composed being successively removed and replaced by others: as regards the breakwater, however, there is the abstraction of its parts without any compensation. For instance; the sea breaks with tremendous weight on Chesil Bank as well as on Plymouth breakwater; the one, however, is sustained by nature, which the other, as we have seen, gives constant employment to a large staff in making repairs, without which, it would soon fall into ruin—a necessity which will co-exist with the breakwater itself. The fact that the materials of the breakwater are larger than those of a beach,

and that they may be compacted together, does not materially affect the question, for workmanship, in a case like this, must in the end prove subordinate to a defective principle. Mr. T. Stevenson has justly termed a beach "the profile of conservancy of the coast"—that is, its contour and slope is the result of all the forces acting upon it, which at the same time give it the best position and form for resisting them,—whereas, with the artificial work under consideration, the slope is not only steeper than that of a beach, but its projection being determined more with regard to the cover to be afforded, than the forces to be encountered, it cannot be expected to have the same permanency, but rather to call into operation a concentration of force, which is first apparent by the destruction caused by it.

It is also urged, that the long-slope breakwater is "to make cheap materials stand in the place of expensive labour." No doubt it has been adopted in several instances from motives of economy, but surely that work is the cheapest in the end which is best suited for the purpose designed, and that it is better to pay the difference of cost at the outset, than to be saddled *for ever afterwards* with an annual expense entailed by the adoption of an unsound principle.

UPRIGHT-WALL—a breakwater of this construction is now being formed in Dover Bay, as one of the results of the Commission before referred to; the work, which is nearly vertical, will be faced with granite from the bottom.

Its merits.—It has been shown, that the wave in deep-water being simply an undulation, would only undulate, or move nearly in a vertical plane against the face of such a work, and would not exert any percussive force, (see also *Treatise*, p. 85) That such a result must follow, is not a matter of opinion or theory only, but one of common observation, and effects are

daily witnessed which might have been predicted, if the principle of a deep-water wave had been duly considered. General Sir Harry Jones, in his remarks upon the profile of breakwaters, observes with respect to Kingston harbour "it is very interesting to watch the action of the sea upon the recently finished circular head of the eastern arm, and at the same time upon the long-slope, where the two descriptions of work unite: against the former, the sea rises and falls without violence, whereas, on the long-slope, the sea breaks and falls upon it with great fury." Sir H. D. L. Beche remarks that, "when engaged during the progress of the geological survey, I was much struck one day on the shore near Fishguard, Pembrokeshire, where many varieties of coast, as regards depth of water occur, with the varied action observable at the same time, according as the water was deep and the cliffs vertical, or the slope of sandy beaches presented itself. The same on-shore sea, which produced a mere flop on the former, caused heavy rolling breakers on the latter, and there were modifications of every variety, tending to show the comparatively small action on the vertical cliffs plunging into deep water." In a letter to Sir Byam Martin on November 24th, 1845, Professor Airey stated, "I was once rowed out of Swansea harbour at high water (with fully 20 feet of water abreast the pier-heads) when very high sea was running. We passed so near to one pier-head, that we could touch it with the oars; but there was no breaking, and no fear of the boat touching the pier, though we were raised and depressed many feet. Before we had left it 200 yards, we passed over a shoal where the sea broke so heavily, that it carried out of the boat the two rowers next to myself, and nearly filled the boat, and with great difficulty we gained the beach. On another occasion, in rowing past some of the perpendicular cliffs descending into deep water on the east side of the Lizard, I remarked the unbroken character of the swell, but on the sands of Cadgwith there was a high surf.

In the same manner, an Engineer of eminence has stated to me how strong was his impression, on seeing the swell unbroken on the cliffs descending into deep water at the Bay-head of Valentia." Major General Pasley remarks, "I have been informed by an officer who served on the coast of Spain during the siege of St. Sebastian, that boats might approach the bluff rocks of that coast on each side of the harbour of Passages with safety when the wind was blowing a gale directly on shore, as he knew from his own personal experience." Captain Vetch, R.E., narrates, "In going out of the little harbour of Scarnish, in the Island of Tiree, in a vessel of 25 tons, we were carried three times up and down a rock inclined to the horizon at an angle of about 60 degrees, with the wind on-shore, and without touching it, though the gunwale was within a yard of it. It was blowing fresh." The writer also, has watched at Lowestoft harbour with great interest an effect similar to that noticed at Kingston. At Lowestoft harbour, a year or two ago, the north breakwater was partly in deep water and partly in shallow, from the eastern elbow meeting the low-water line of beach. Abreast the deep-water part (as at Kingston) the undulation rose, fell, and rebounded without disturbance, at a time when the breaker was dashing violently against the other portion of the breakwater, and throwing its spray far across the harbour within. The same effect may be noticed at any wharf-wall, a boat alongside which will rise and fall with a tendency to retire from the work, rather than to strike against it.

Of course the summit of the upright-wall breakwater will be exposed to the effort of the broken crests of deep-water waves, but this, as has been already shown, will be comparatively powerless against the inertia of such a compact mass—a property which also renders it far superior to the long-slope, when placed within the region of breakers.

Its drawbacks.—With the experience of the fate of long-slope breakwaters, and a more intimate acquaintance with the phenomena of waves, it is not to be wondered at that the principle of an upright wall in deep-water should be advocated by the great majority of scientific men in the present day, but considered merely as a structure, it may nevertheless be reasonably urged against it, firstly, that from the necessity which exists for levelling the bottom and using the diving bell—for forming the work of the best materials, not liable to deteriorate from the action of the sea-water, and that the outer facing blocks should be very heavy, with the joints well closed and cemented, such a work can only be executed at enormous expense—and secondly, that it must always be liable to wreckage, either from the constant action of the sea searching through every joint and acting upon a mass without continuity—or from defective workmanship—or from a treacherous foundation, a circumstance which would perhaps only be discovered after the work had been carried out by the cracking of the wall, and the consequent disintegration of the entire structure.

Another description of breakwater, partaking partly of the character of the long-slope and upright-wall, in progress at the Tyne and at other places, is said to be a recognized mode of building, and the result, as it were, of the experience hitherto gained. That at the Tyne, for instance, is formed of *pierre perdue* (or loose stones) up to low-water mark, and then has an upright-wall reaching to 24 feet above high-water springs, with an esplanade and quay within it. This mode of forming breakwaters is yet to be tested, but remembering what forces it will have to encounter, the writer is of opinion, that it will be found defective. Experience will probably prove, that while it has the breaker forming property of the long-slope breakwater, it lacks the power of resistance of the upright wall.

FLOATING.—Floating breakwaters, being more creditable to the ingenuity than to the practical soundness of their projectors, have not received much public support—there is a general belief in their insecurity, and consequent inefficiency.

The statements of the advocates of floating breakwaters, that they are economical and easy of construction—that they are adapted to any depth, and that they could never cause the deposition of silt, as they admit of an unobstructed passage to the tidal streams, are more than met by the counter-statements of their opponents, viz., that they would be subject to considerable delapidation from friction and corrosion—that they would have a tendency to shake to pieces—that they would be subject to the ravages of the worm—that they might be burnt, or set adrift by an enemy in time of war—that the wave would pass beneath them undiminished in height, and lastly, that their breaking adrift in a gale (a very likely occurrence) would endanger the safety of vessels anchored under their protection. These, and other considerations, appear to have influenced the Select Committee upon Shipwrecks in arriving at a conclusion unfavourable to such structures; a conclusion held to be sound by men of reflection in the present day.

To recapitulate—we have seen

First—That experience is entirely against the use of a long-slope breakwater as a means for resisting waves, and that the various causes of its weakness are apparent after a careful consideration of the *rationale* of the wave itself. The facts brought before the Harbour of Refuge Commissioners of 1844 were conclusive upon the point; in addition to which, out of 19 persons at the head of science in this country, and whose opinions were taken on the occasion, 14 were decidedly opposed to a mode of construction which has been properly defined as "rude and unscientific, being a means of procuring

the smallest amount of resistance with the largest quantity ot materials."

Secondly—That though an upright-wall breakwater (like that at Dover) is correct in principle, its construction involves an enormous outlay, in addition to which, elements of weakness might subsequently be found to exist, the presence of which would, sooner or later, cause its destruction.

SECTION III.

REFUGE HARBOURS—PRINCIPLES, ETC.

Breakwaters have been described as a means for defending and forming refuge and other harbours. It will now be shown to what extent the character of such harbours as regards permanence and protection depends on the construction and projection of the breakwaters enclosing them.

The process of silting.—One of the most important considerations which the subject embraces, is the encouragement which such works usually afford to the process of silting—that is, the deposition of the detrital matter with which sea-water in the vicinity of a coast is always more or less charged.

When a coast is composed of materials such as clay, fine sand, and other substances of a like nature, it is readily acted upon by water in motion, and whether the motion be that of the wave, or be simply due to the tide-stream or current, the particles of matter disturbed by it will be held in suspension by a mechanical power which is the property of water under either circumstance. Upon the eastern coast of England, for instance, during gales of wind, the wave exerts its influence in disturbing matter at a depth of 15 fathoms, and in along-shore winds, when the wave is comparatively small, or about 6 feet, it will lift matter from a depth of 6 fathoms. The action of the current also as a disturbing and transporting agent may be observed on a calm day by looking over a boat's side at the passing stream, when it will be noticed, that the water moves in endless convolutions, and is charged with matter, the

presence of which in this case, is the result of the friction, or the brushing action of the current over the bottom.

When, however, these disturbing influences are in abeyance, and the water is at rest, it loses its holding property, and the particles of matter being forced to subside from their gravity, are deposited in the first place of rest. It is owing to this process of alternate suspension and deposition being constantly in operation upon every sea-board, where the above-mentioned conditions obtain, and are in no way interfered with by artificial works, that the equilibrium of the features of foreshores is preserved—in other words, the amount of soil upon the foreshore will seldom increase or decrease by any sensible amount. Important as it is to keep this principle clearly in view, it has but too frequently happened that harbour works have been constructed in total disregard of it.

A striking instance of the important part performed by the current in the operation, is supplied by General Pasley, who mentions that "he found the interior of the Royal George, sunk at Spithead, silted up 29 feet, though externally there was little or no accumulation." Another illustration is supplied by a common characteristic of a sea-board—namely, every bight or bay being sandy and shallow, while the bounding points are steep (*Treatise* p. 93). In this case it will be evident that the coast stream is concentrated upon the point, but deflected from the bight, and the weakened stream which laves the indenture, having its power for disturbing and suspending reduced, there will consequently be an accumulation of soil in the bight.

A distinct recognition of this truth and its practical character, was made by the writer on two occasions. In 1845, when it was proposed to form the south outlet of Sunderland South Dock at the head of a shallow bight, the writer was applied to for his opinion, and the following is an extract from his letter to the Directors :—

"From its being at the very head of Hendon bay, the sand would rapidly accumulate about it, and a few years would serve to shoal up what is now deep water. Sluicing, the only means for effecting a clearance, would merely moderate the evil, and remove the bar a short distance from the pier-heads, instead of its being betwixt them,—indeed, I feel justified in predicting, that if the plan be adhered to, it will entail the evil of a dry bar outside the pier-heads. It is of little use saying, 'there's deep water where the entrance is proposed to be built,'—being in a bight, sand must rapidly accumulate on either side, and in front of it."

This opinion, it will be perceived, had reference to the Dock solely, and had no connection with its effect upon the port generally. After some hesitation, the original projection was abandoned altogether, and the outlet has been made in the position and nearly of the form recommended by the writer, and the result has been, that instead of being encumbered with a shallow frontage, the threshold of the outlet is swept clean and kept free from accumulations, by the coast streams acting directly upon it.

Again; in August 1850 the writer was ordered to report upon the probable effect of the works then being advanced seaward to the southward of Sunderland harbour in embaying the latter, of which report the following is an extract:—

"Originally, the entrance (of Sunderland harbour) stood boldly forward beyond the general line of coast on either side, and from thus forming a point directly across the set of the coast-tide, a narrow bar close to the pier-heads was constantly maintained, but when they (the works alluded to) are fully carried out as proposed—the pier-heads placed in a bight instead of upon a point, and the coast-tide deflected away from the harbour, I am fearful that sand will lodge in considerable quantities in and about the entrance, and widen the bar."

So permanently shallow has the frontage become, that it is now (1858) proposed to construct works which would restore to the outlet of Sunderland harbour somewhat of the position it occupied relatively, before the protruding southerly works were carried out.

It is wise to recognize broad facts, for if this absolute connection of the features of a seaboard with the deflection or otherwise of the tidal streams had been kept steadily in view, and it had at the same time been borne in mind that in nature, like causes always produce like effects, many of the mistakes which have been made in harbour projection would have been avoided.

Close harbours fill : Cases, &c.—It will be seen by the following extract, that the writer drew attention to the fact that close harbours fill,* while reporting against forming a close harbour at Hartlepool—a work for which there was no difficulty in obtaining the sanction of Parliament, but which, happily, has not been carried out.

> "The great agents of change upon all sea-boards are the waves and the currents, tidal or otherwise; the former in destroying and disturbing, the latter in suspending and trans-

* The operation of deposition in such a case, is clearly described by Smeaton, who, while he was the father of modern hydraulic engineers, was also one of the soundest. He observes in a report upon Ramsgate harbour, "The tidewater upon this part of the coast is charged by a considerable quantity of mud and sandy matter, whenever it is agitated by the wind, accompanied by a quick-flowing tide. This silty matter being thus carried into the harbour along with the water that contains it, and there finding a place of repose, settles to the bottom; and as there is nothing to raise the mud upon the reflow, the water quietly ebbs out of the harbour, leaving the silt behind: and as the same cause constantly operates to produce the same effects, a continual increase of silt must be expected to take place." And further on—"This is the natural tendency of all harbours, for wherever there is mud or matter to deposit, an addition to the soil is the natural consequence of a place of repose."

porting, and the various modifications of these mechanical processes are all apparent to common observation. Matter suspended in water, and depending on motion for its support, is deposited upon entering a harbour or other sheltered place, the time in which it is so deposited depending on the gravity of the matter—the repose of the water, and the depth of descent, and, as a general fact (with singularly few exceptions), these accumulations gradually increase in all closed harbours, or still-water basins, according to the varied circumstances of exposure, surrounding matter—extent of surface, and depth." —*Report on Hartlepool Refuge Harbour, March* 31*st*, 1855.

We have defined harbours, as at present constructed, to be enclosed spaces, from whence the wave and current are excluded by the interposition of breakwaters, and it has been shown that there must needs be a continually increasing deposit wherever highly charged water passes into a still basin. Whatever, therefore, be the turbulence of the sea, or the rapidity of the current outside such a harbour, and the consequent capability of the water for holding matter in suspension, the conditions within the harbour will be altogether different, for as the suspension of matter is simply the result of wave and current motion, it must follow that such suspension cannot continue when the motion is destroyed—the amount of matter held in suspension in the one case, and deposited in the other, will, of course, depend on the nature of the coast—on the forces acting upon it, and also on the degree of rest which prevails over the enclosed space by the more or less perfect obliteration of those forces.

Dover refuge harbour, which is intended to be a close harbour on a grand scale, enclosing by upright-wall breakwaters a space of 700 acres, furnishes us with an illustration to our point. Through the comparatively narrow entrances into the harbour, there will be only the weak current due to the passage of the tidal water which fills it. The water in

front of Dover is, in boisterous weather, highly charged with matter, and it has been estimated that if the amount of material which was shown by Captain Washington's tests to be present in the water at such times, should be all deposited within the enclosure, it would reduce the depth throughout by 6 inches annually. It would be, however, exceedingly difficult, if not impracticable, to determine the exact quantity of matter in any sea-frontage, for during Captain Washington's experiments it appeared that the amount held in suspension varied at different depths, and that it was carried in wreaths or eddies, which agrees with what has already been advanced about the gyrating movements of the water of a current: the average of the observations may therefore after all but inadequately represent the matter suspended by, and capable of being deposited from the water of Dover bay.

A few facts gathered from that neighbourhood lead to the conclusion that Dover harbour will be subject to extensive silting. The cinque ports in the vicinity have all become lost from accumulations of shingle or deposits of mud, and the same causes which choked those harbours are at work now, without any modifying circumstances being present to counteract accumulations. In Captain Washington's letter to the Secretary of the Admiralty of March 1st, 1845, it is stated that, "in Ramsgate harbour to the eastward, with an area of 42 acres, the deposit is 2 feet in depth in a year: at Folkstone to the westward, with an area of 14 acres, it is the same: in Dover harbour, with an area of 28 acres, there is every reason to believe there is quite as much." Here the question arises, will the deposition in the large close harbour be greater or less than what it now is in the smaller enclosures? In giving evidence upon this subject on the 17th May, 1844, the writer in answer to the question, "Do you apprehend any silting up in any harbour, if constructed in Dover bay, through the matter held in suspension during westerly gales or otherwise?" replied,

"It would share with Ramsgate harbour as to this particular, but in a less degree at Dover, as it would have a greater space to fall through before being deposited."

A more extended experience, however, has led the writer to doubt the entire soundness of the opinion he then expressed, for he has since observed in the examination of several deep-water harbours, that the greatest quantity of deposit always occurs in the deepest portions, and that it should be so, will be manifest after a little reflection. It has been explained, p. 7, that the extent of the sub-action of a wave bears a certain proportion to its magnitude, and also on p. 31, that a 6-feet wave on the east coast of England will disturb matter at a depth of 6 fathoms, which is six times the perpendicular measure of the wave itself. Now, allowing it to be possible for a 3-feet wave to be generated within the space of a refuge harbour like that at Dover, then, if we are correct in adopting the above proportion to determine the limits of disturbance, it will result, that below the depth of 18 feet, there will be a region of motionless water, to which matter will be constantly committed from the super-imposed water, and through which it must fall to the bottom, where, not being subject to any disturbing influence, it will remain as a permanent deposit; and, on the other hand, that where the water has a less depth than 18 feet, material which has been deposited during a period of rest, will be liable to be turned up and borne elsewhere; thus, the quantity of deposited matter remaining after a given time, will be greater in the deeper portions of the space.

It has been supposed that there would be less matter deposited in a large harbour than a small one, because, it is said, that the larger harbour being advanced further sea-ward, would have its entrance in clearer water: this, however, would not be the case, for the action of the tide-stream would convey the highly charged water of the strand into any harbour, however far out its entrance might be placed. The surface drift, or

the particles blown off from the quays, may be expected to add to the quantity of matter in a small harbour; still, the quantity derived from this source will form but a small portion of the whole amount deposited.

Small dry harbours like those alluded to are, however, in one respect, more favourably circumstanced for retaining a proportionally smaller amount of deposition than a capacious refuge harbour with the bottom always water covered, similar to that now being made at Dover. In the former, there is during high winds, a scavenging operation going on, which the writer has often watched very attentively; unimportant it might appear to the casual observer, but nevertheless very effective in its working, is the repeatedly plied stroke of the miniature breaker over the surface soil of such harbour, as the ebbing-water is about to leave it—for by this means, there is imparted to the water a considerable portion of the lighter matter which had been deposited during the previous flood, and which would have accreted, had no such agent* followed. This operation may be observed in a blustering day in any harbour which is being left dry, and which possesses sufficient space for the formation of even the most diminutive lipper.

It has already been shown, that whatever is deposited in the deep refuge harbour below a certain depth, must there remain, unless it be removed by artificial means, and it is the writer's deliberately formed opinion, that the future is, for Dover harbour completed, not more promising in this respect, than the present condition of the small close harbours of Ramsgate, Folkstone, &c. We are not, however, left wholly to conjecture upon this point, for several instances of harbour construction within the writer's experience are highly suggestive, showing, as they do, what is really involved by enclosing water highly charged with detrital matter.

* It is by the same simple process, that muddy and sandy flats in rivers are kept nearly at the same level for centuries.

As one example. A harbour was begun at Lowestoft in 1846—the circuit of which was completed in January 1847, and it was generally put out of hand in 1848, when there was a space of 18 acres, enclosed by breakwaters projecting boldly into the sea, somewhat like those at Dover, thus constituting it a close harbour, from which the wave and current actions were nearly entirely cut off. In 1847 the writer examined it, to ascertain its existing state, and with a view to determining the changes which might afterwards take place. Observing that the harbour was fronted by sands from whence the wave might be charged in heavy weather, and that it was upon a shore of moveable materials, upon which an oblique drift was constantly going on, the writer reported to the Hydrographer on the completion of the examination as follows :—

> "I am inclined to believe, that when the piers are completely filled in, the harbour will be found to suffer more from a tendency to silt up, than from anything else—indeed, where the back-water is so trifling, and the flux and reflux so sluggish, I do not see how it is to be kept open except by continuous dredging"—and about the accumulation of sand at the back of the north breakwater, "it remains to be seen, whether its further advance will not cause a serious obstruction at the outer entrance."—*Dec. 20th*, 1847.

In 2½ years afterwards, when the writer examined it again, it was found that the shallow portions had not materially altered, but the deeper parts of the harbour had silted up 10 feet on the south side, and 6 or 7 on the north side ; every subsequent inspection showed that the evil was increasing, and at this day the enclosure is merely a shallow basin, through which a channel is only maintained by constant dredging. In 1856, when the writer last visited Lowestoft, the groyne-like effect of the north breakwater, in accumulating the coast drift, which had been foreseen, had caused the shore north-eastward of the harbour, to advance outwards from the heel to

nearly the line of the head of the breakwater, a distance of about 500 feet.

Take another example. In September 1847, the writer visited Grimsby to make certain tidal observations in the vicinity of the Dock then forming there, in order to be abel to estimate what effect the stream would have upon the soil about the Dock entrance, and the Roadstead in front of it. Now the ordinary features of a sea-coast to which we before referred, are, in a river, always reversed, the points being shallow, and the bights being steep, and this fact had a direct practical bearing upon the projection of the Dock at Grimsby. The following was the way it was applied by the writer in his report to Sir Francis Beaufort:—

> "The new dock forms in itself a point; accordingly, it will in time be troubled with the evil common to all points in rivers—viz., shoal water in front of it; a tendency to silt up will exist within the dotted line marked on the sketch. The jetties forming the sides of the entrance-basin are to be composed of open piling to admit the passage of the tide through them; still, if deposit forms to the entrance of the basin, it will be the same (as far as the tide is concerned) as if they were constructed solid. At present there is still-water 300 feet in front of the works during the strength of the ebb."—*Sept.* 11, 1847.

No one who has seen the muddy water of the Humber, will be suprised to learn that under such circumstances, the prediction of 1847 has come true to the letter, and that sluicing and dredging appear to be equally powerless for overcoming the evils which have resulted from the erroneous projection of the work. It is now pretty evident, that if an approach to Grimsby dock is to be maintained, it can only be at an expense which would seriously interfere with the success of the scheme.

To continue the illustration. Howth harbour on the coast of Ireland, has become choked with sand and nearly useless,

while Kingston harbour, but a short distance from it, remains nearly as free from deposit as on its first formation. The reasons for this difference were stated by the writer on the 31st March, 1855, while reporting against the formation of a close harbour at Hartlepool. It may be sufficient to state here, that Kingston harbour is comparatively free from accumulation, simply because the water which fills it is nearly free from suspended matter.*

In the Refuge harbour at Holyhead, it was ascertained at a late examination by the writer, that notwithstanding it is generally the receptacle of clear-water, 15 to 18 inches of deposit have already formed in the deeper portions of it.

Even in Plymouth Sound, which is only partially closed or covered in by the breakwater, and where the tidal streams are comparatively free, indications are not wanting of an increase of soil, particularly about the breakwater itself, as well as at other parts: the breakwater at Cherbourg also appears to have the same effect.

That nothing is observed in nature analogous to a close harbour in any situation where the water is charged with matter, except it be in a choked state, should be sufficient to decide the case against them. Those natural inlets which approach to a close harbour in form, are in nearly every instance of considerable extent, and connected with arms running well inland, so that they are kept open by the tidal movement—or they are upon a rocky coast with clear water.

The Harbour of Refuge Commissioners, in their report of January 28th, 1846, while expressing strong doubts that any effectual remedy would be found for it, state, "It is not our purpose to contend for what is in truth, practically impossible,

* Sir W. Cubitt, in his evidence before the Harbour of Refuge Commission said "I know Kingston very well—I have watched it tide after tide, and week after week sometimes—the clear ocean water there comes in clear—quite blue."

as it is manifest that the greater part of whatever sedimentary matter may be held in the water flowing into a harbour, will fall to the bottom with more or less rapidity in proportion to the stillness of the water within, and only such portion of the lighter matter, as from its less specific gravity may remain in suspension, will be carried out by the ebbing tide."

There is another point beside those alluded to, which appears nearly to have been lost sight of. The groyne-like effect of a harbour projected like that at Dover, must, where there is any marginal drift, ultimately cause an advance of the foreshores on either side of it, similar to that we have noticed at Lowestoft. On one side, the accumulation would be that of the drift itself, and on the other it would be from matter driven into, or deposited within a space where its removal could not be effected by wave and current action. The effect of the advance of the foreshores towards the entrance of the harbour, is to increasingly charge with matter the water which fills it. It is true, that the time when Dover harbour would suffer materially from such a cause, may be very remote, but still the point should not be overlooked when considering principles of projection.

It has been advanced by the advocates of close harbours, that if the current entering the harbour have a less rate than the current sweeping by the entrance, there will be less tendency to deposit. This appears to be unsound, for unless the water becomes clarified immediately, or shortly after it leaves the main current, the stream which delivers the harbour supply must be as impure as the other. The very conditions here contended for, exist in the cases of Lowestoft and Grimsby, where we have seen that they have not the least preventative effect. When this theory was proposed to Professor Airey, he replied very pertinently "I do not think that that bears very importantly upon the question."

It is hoped that sufficient has been already advanced upon

the subject to show, that while it is quite safe to form a close harbour in a situation where the waters are as free from matter as at Kingston, it would be equally unsafe, and in disregard of all experience, to attempt it within the limits of the heavily-laden waters of the eastern coast of England, where any close harbour must, in the end, prove only a stilling-basin—a clarifying pool, and a mud-trap.

It should be clearly understood what is really involved by this error in principle, for, in truth, it is no light matter. It has been estimated, for instance, that it would cost about £20,000 to remove by artificial means the six inches of deposit which it is supposed will form annually within Dover Refuge harbour when it has been completed, an outlay which would, of course, have to be incurred annually *for ever afterwards*, if the harbour is to be kept open.

It is hoped, that from what has now been offered respecting the character of waves, the defects of breakwaters, and the projection of harbours, the reader will be prepared to admit that to meet the various requirements of harbour-building, and to insure success for the future, other means than those which have hitherto been resorted to are necessary to overcome the obstacles presented by nature.

It surely must be evident, that—

Breakwaters in their construction should be free from those defects of principle, which subject the long-slope to constant wreckage from the direct and oblique strokes of the wave.

They should partly produce the effect of the upright-wall, without involving its drawbacks of costliness and imperfect construction.

They should possess continuity—a property belonging neither to the long-slope nor the upright-wall, where the weakest part is the measure of the strength of each structure.

They should be inexpensive, so as to admit of their being established in every situation where shelter is required, and where the nature of the frontage will admit of its being afforded.

Their construction should be of such a nature, as to admit of their being inspected and repaired when necessary.

And, unlike the long-slope, or the upright-wall, they should be capable of removal in case of faulty projection, or a change in local conformation, such changes in nature being of frequent occurrence.

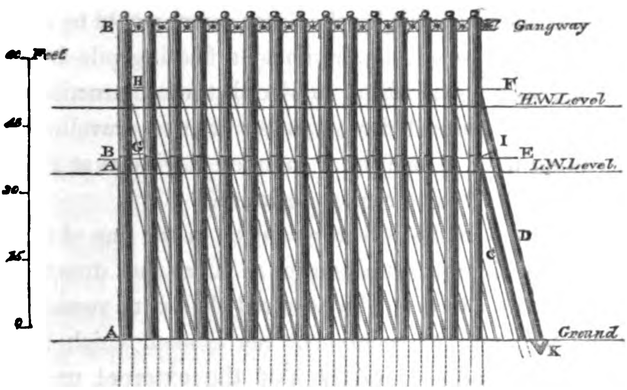
Breakwaters in their projection should be arranged more with the view of forming a protected roadstead, which is wanted, than a close harbour, which is not wanted, and which, as we have seen, is defective in principle, and destructive in practice. To this end, breakwaters should be projected so as to insure the unobstructed passage of the tidal streams—the destruction of the surface-breaker, and the interception of only so much of the deep-water undulation, as may be necessary for the security of the vessels anchored within their protection.

The way in which these several objects are to be attained, will be pointed out in the next section.

SECTION IV.

WAVE SCREEN—ITS EFFECTS.

Fig. 1.



The Wave Screen; *Its Construction.*—The structure depicted above, and named a Wave Screen, from the nature of the work to be done by it, is arranged for a low-water depth of 36 feet—a tidal rise of 15 feet, and a wave of 15 feet. It consists of nine principal parts, viz., A A and B B, lower and upper courses—C and D, lower and upper stays—E and F, lower and upper ties—G and H, lower and upper link bars—and I, the stay chain. The foot of each stay is furnished with a heavy shoe as K in diagram, (fitted so as to be perpendicular to the plane of the ground,) to be buried beneath the surface by the action of the tidal current, while the ties are fitted with moveable flanges to secure the various sections of the screen in their places, and to provide against irregularities of distance.

The materials to be used for the construction of the Screen would be pine scupper-nailed—or pine cased in green-heart, or wrought-iron cylinders, for the lower course, and either cast iron or wrought iron cylinders, for the upper course, and for the upper half of the longer stays. The ties, flanges, link-bars, stay chains, and shoes, would be of wrought iron.

The lower course of piles or cylinders, would be driven ten feet into ground consisting of clay or sand, but in the case of a thin layer of soil over a hard sub-stratum, then another mode of fixing and securing the lower course would be adopted. The lower course would be driven by a floating pile-driver, or, after a few sections had been so placed, the construction of the work would be proceeded with, either from a travelling platform resting upon it, or from a common staging as at Portland, as circumstances might render desirable.

The direction of the Screen would be in the line of the tide-streams at their greatest strength, as far as that direction was consistent with affording the required shelter to vessels. The intervals between the sections of the Screen, which it is intended should admit exactly half the external undulation when advancing from abreast, would be determined by experience during the progress of the work.

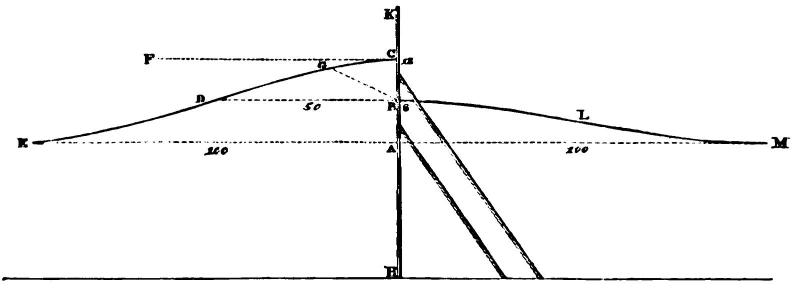
The diameter of the lower and upper courses being regulated by the depth of water and weight of sea, would, for a Screen in a low-water depth of 36 feet, be 20 inches, and that of the lower and upper stays, 15 inches: the iron of the cylinders would be, at least, an inch in thickness. The junction of the lower and upper courses of the Screen would generally be 3 or 4 feet above the low-water level, while the height of the summit of the Screen above high-water springs, would depend on the maximum height of the wave.

The form of the various parts of the structure would be cylindrical, that it might the more easily resist the broken crests of deep-water waves, or the batter of artillery, while the

employment of iron for the upper portion, would render it equally independent of fire.

The Screen would carry a gangway along its summit, and be lighted at night.

Fig. 2.



The forces acting against it.—The first consideration respecting such a work must embrace the nature of the forces to which it would be exposed; what is their power, and what the power of resistence possessed by the work. It has been already shown by various illustrations in Section I., that a deep-water wave undulates against an upright cliff, wall, or other object presenting the same profile—hence, it would undulate against the screen. The influence, therefore, which the undulation and its broken crest would exert upon the Screen, is that which is required to be known.

All the illustrations of the property of a wave which have been given, show that the Screen would not be subjected to percussive force—if, for instance, the particles in proximity to the Screen, H K in Fig. 2, undulate vertically between A and C, and never move towards it, how can they administer a stroke to the Screen? If, as has been observed, the undulation was really a body of water advancing with the rapidity of the wave itself, then its percussive force, like that of a solid, would be in proportion to its momentum; but it is self-evident that there can be no stroke against a perpendicular object in the absence of any horizontal motion!

Nor is it hydrostatic pressure, which pressure is equal to the weight of a column of water whose base is the surface pressed &c.; this pressure is that sustained by dock gates with a head of water on one side of them, and which pressure, allowing H K in Fig. 2, to represent the gates, would be conveyed in horizontal lines as F C, a direction, as will be perceived, different from that of E D G C, the containing, or bounding line of the undulation.

If then the influence exerted by the wave be neither percussive force nor hydrostatic pressure, what is it? Upon going carefully into the question of the nature of the undulation, it seems but fair to infer that the Screen opposed to it would only be partially subject to the *weight* of that portion of each undulation due to the difference between the levels of the water on the seaward and landward sides of the Screen. The incumbent water on the exterior side of the Screen would require support in proportion to its height and width, and the Screen would supply the necessary resistence to give that support. There is an analogy between a fluid and a solid in this particular, for the water would rest against and be upheld by the Screen, somewhat in the same way as a log of wood, or other material, inclined from the perpendicular, would rest against and be upheld by a wall, or other supporting body, with this difference, that whereas the whole log bears with a part of its weight upon the wall, only a portion of the exterior and intercepted fluid bears upon the Screen, for reasons which will be stated presently. This being admitted, then the weight of any given height of water resting against the Screen may be arrived at by considering the alteration of form and the various changes to which the undulation would be subjected by the interposition of a partial barrier like the Screen. Here a considerable degree of attention is necessary, as the soundness of the proposal will entirely depend on the accuracy of the inferences which are to be drawn—it is only by induction that we

can arrive at the truth, for, as Smeaton said in allusion to waves at the Eddystone—their power is subject to no calculation.

Allowing, for example, that such a screen be established on the eastern-coast of England: we have assumed that in a gale on that sea-board, a deep-water wave measures 15 feet in height from base to summit: it has also been estimated, for reasons stated on p. 12, that such a wave advancing towards a solid upright barrier, would become reduced by the recoil of the preceding wave, one-third of its height: the undulations seaward of such barrier would, therefore, present a combination of direct and reflected waves of the general height of 10 feet; but as the Screen would not be a solid barrier, the reflection, consequently, would be less perfect, and if the reduction it would effect in the height of the undulation be stated at one-fifth instead of one-third, it would follow that no wave of a greater height than 12 feet from bottom to summit could reach a Screen so placed.

It has been mentioned that the intervals between the various sections of the Screen would be of the required width to admit of the passage of half the undulation when approaching from abreast; that is, supposing a 12-feet undulation to arrive at the Screen from seaward, only so much of it would pass, or fall through the intervals of the Screen, as would form a wave of 6 feet on its landward side. In figure 2, for instance, as the wave E D G C was gradually rising on the seaward side of the Screen from A to C, a height of 12 feet, the water which passed or fell through the Screen, should, in the same time, raise the level from A to B, a height of 6 feet, on the landward side of the Screen, and the direct effect in such a case, therefore, would be to reduce the undulation E D G C to the undulation B L M, or to half its former size. As the weight of water resting against the Screen would depend on the difference of the water-level upon its two sides, it follows therefore, that of the 12-feet undulation, only that portion of E D G C

which is above the horizontal line B D, the level of the summit of the inferior undulation, would exert upon the work any of the pressure due to weight.

The length of a 15-feet wave is about 200 feet (which would also be its length when reduced in height to 12 feet) and half of this length, or A E, being 100 feet, would give for the triangular space of water D B C above the horizontal line D B, a base of 50 feet, and a perpendicular of 6 feet, which, with a breadth of 20 inches (the diameter of the cylinder) represents a weight of 7 tons nearly. Now the water within this space is not like that contained within a vessel, where there is an equal pressure downward and sideward—here, gravitation alone acts, and as this is necessarily in a vertical direction, it will be evident upon projecting the figure, that by far the greater portion of the water contained within the triangular space D B C, would be resting upon the base D B, and not against the perpendicular B C. The quantity actually exerting any of the influence of weight against the perpendicular, or Screen, B C, can only be arrived at by inference, and admitting that one-quarter of the water within the triangular space alluded to would have a tendency to rest against the Screen (and this is evidently far in excess of the fact) it reduces the quantity to about one and three-quarter tons. It is clear, however, on the slightest reflection, that on account of the action of gravity, the Screen would not be subjected to the dead-weight of the water contained within this reduced space, on the same principle that if the inclined log be lifted away from the wall, it will be found that the latter has only been supporting a small portion of the actual weight of the log; each cylinder, in short, would only be subjected to the "push" of the mass, and not to its whole weight—accordingly, the foregoing estimated quantity may again be reduced by one-half, which gives seven-eighths of a ton as the approximate weight of the water which rests against, or is supported by

each section of the Screen. This, though very nearly, is not quite the whole of the case, and we must here make use of another diagram :—

Fig 3.

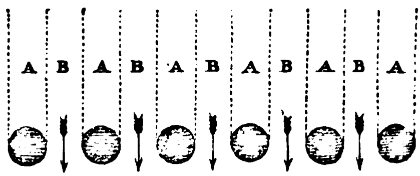


Figure 3 is a bird's-eye view of a portion of the Screen, A and B representing alternate sections of the undulation on the seaward side of the Screen; the water within the spaces A would rest against, or be sustained by the cylinders, while that within the spaces B would pass through the intervals of the Screen, and form the reduced undulation within it. Though the particles of water move among each other freely, yet the filaments passing through the intervals of the Screen from the spaces B, would have a natural adhesion to the water in the spaces A, and the effect of the friction arising from such adhesion, would be to add somewhat to the weight of water resting against the exterior side of the Screen. What that addition would be could only be determined by experiment, but that it would be too trifling to materially affect the estimated quantity resting against each cylinder, may be proved by analogy. If, for instance, on a windy day, the reader had a person standing closely on each side of him in a direction transverse to that of the wind, he would feel but little extra pressure of the wind in consequence of their neighbourhood, and the same rule holds good whether the fluid be air or water. This effect of the passing water has only been alluded to to show that the point has not been overlooked.

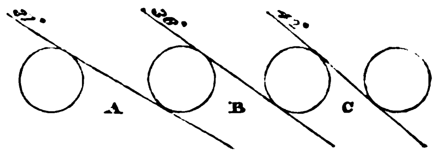
Less than a ton would therefore be a close approximation to the weight of water resting against each cylinder of the Screen, but individually, and separately, they would be equal

to the support of several tons, and when it is considered that their power would be increased many-fold by the combined support of the adjoining sections, and by the continuity of the work, it will be evident that the power of resistance possessed by the Screen would greatly outbalance any force which could possibly be brought against it. It must also be borne in mind that there is no analogy between the Screen, and the boats and bulwarks of a ship, for the broken crests of the deep-water wave would be powerless against a structure presenting no long line of resistance, and which would permit the sea to play freely round its parts. Sunderland beacons, for instance, spars stepped in the rock, 33 feet long, and without stay or support, resist unharmed the bursting sea of the heaviest gales. The extent of immersion also, would render the Screen nearly independent of the surface stroke, on the same principle that a pole buried well in the earth is better fitted to resist the pressure arising from sudden gusts—the parallel, though not exact, is sufficiently so for the purpose of illustration. That the summit of the Screen, also, which it is intended should be 19 feet above high-water springs, would be sufficiently clear of the surface-lash and spray, will be evident from the fact, that upon the staging at Portland, which is 18 feet above high-water, waggons and locomotives are constantly running even in the heaviest gales. Upon this point Mr. Coode, the resident engineer, remarks, "in the entire eight and a-half years that we have been at work at Portland, we have certainly not stopped twenty days from bad weather."

The intervals between the sections of the Screen, as has been mentioned, would be of the required width for admitting half the undulation when it advanced direct upon the barrier, but when its advance was oblique to the line of the Screen, the interception would be increased in proportion to the obliquity; and it will be evident that at a certain angle (depending on

the width of the intervals) the Screen would present no spaces, when the interception and deflection of the undulation would be nearly as complete as if the Screen were a continuous wall.

Fig. 4.



The angle of complete interception for the various openings is shown in figure 4, where A, B, and C, represent respectively, whole, three-quarters, and half intervals.

From the foregoing facts and inferences it will therefore be clear, that while the stability of the Screen would be amply sufficient to bear and deflect the deep-water undulation and destroy its crest, the summit of the work also would be above the influence of the heaviest sea.

The effect of the Screen.—The Screen would always be formed in the line of the core of the tide-streams in accordance with the governing principle of its construction and projection, namely, the interfering as little as possible with the natural agencies so as to insure permanency of depth, a principle entirely disregarded in the formation of a close harbour, where mechanical action is intercepted and set at nought. The principle of the Screen would, as we have seen, secure a sufficient degree of undulation and the unrestricted range of the current over the refuge harbour enclosed by it, and so far approaches very closely to the idea of a perfect harbour as described by Sir Wm. Cubitt in his evidence upon Dover. Such harbour ought, he says, " to have the openings large enough, so that there might be both a run of tide through it, and sufficient action to have the properties of a good harbour, as a roadstead harbour, and sufficient motion to keep it from filling up, and that is the

point to which the whole essence of harbour-making must be directed—so that it will not fill up, and so that it will be quiet enough."

The appearance of the sea in gales has no doubt led to the idea, that nothing less than massive stone barriers are equal to resist its force, and the substitution of a Wave Screen for a stone breakwater as the result of a calm consideration of the *rationale* of a wave, would be, as it were, to put a child to do the work of a giant, and to do it much better.

The breaking of the crest of the wave, which is the principal cause of vessels parting from their anchors, owing to the sudden jerk brought upon the chain, and which, as we have seen, may be readily reduced by apparently trifling means, would be completely destroyed by the confliction of the particles in passing through the Screen, and when once destroyed, it could not form again, as explained on p. 10. The surface-breaker would be as effectually destroyed as it is at Plymouth, where, Mr. Stuart says, "the sea is completely broken and lost when it rolls over the breakwater."

When the direction of the undulation was oblique to the line of the Screen, the deflecting effect of the latter would render the interception of the undulation nearly complete, and the interior space would be comparatively smooth; at other times, so much as half of the wave would find its way through to assist the current in maintaining the depth within. This reduced undulation would not, however, interfere with the safe anchorage of the vessels in the harbour, and it is better to sacrifice tranquility, than to incur the greater evil of the harbour filling up.

Much misapprehension exists as to the requirements of a refuge harbour—the repose which is necessary in a dock for trading purposes is not wanted, but only shelter from the tempest. It is necessary that a refuge harbour should possess ample space, and be so projected that vessels of the largest

class would be enabled to enter and ride safely in it under all circumstances of tide, wind, and weather, and that there should also be equal facility for quitting it; the matter of tranquility is altogether secondary. Now the refuge harbour formed by the Screen would, as it were, furnish a roadstead like that at Yarmouth, without the objectionable features of the latter, for whereas the roadstead in question is only comparatively smooth towards low water, when the breakers expend themselves upon the covering sands, the refuge harbour would be equally affected at every period of the tide from the uniform operation of the Screen, and it would also have an advantage over the roadstead in affording less space for the surface-crest to re-form.

Entrance to a refuge harbour thus formed, would be either round the ends of the Screen, or through an interval left in it, according to circumstances; in the latter case, vessels taking refuge would have the inestimable nautical advantage of being able to pass into the body of the harbour without touching brace or sheet, instead of having to present their broadsides to the sea. The nature of the Screen would allow of this central entrance being narrowed or widened, and even its aspect changed, by the addition, removal, or redisposition of a few cylinders on either side, a manifest advantage over the system at present pursued, where a mistake in projection is altogether irremediable. The larger wave which would be admitted by such an interval in the Screen would be almost immediately destroyed by the interior expanse. Sunderland harbour affords an instructive example of this sort—there, the wave on entering an expanse becomes lost in a distance of 200 or 300 feet, and at West Hartlepool harbour also, the wave becomes, from the same cause, reduced from a height of 8 or 9 feet to 6 inches, in a similar distance. The sheltered expanse of the refuge harbour would also, in a similar way, have the effect of quickly dissipating that portion of the undulation which found its way round the ends of the Screen.

The Screen would be superior to a solid breakwater in the case of a vessel accidentally getting alongside it, as she would be influenced by the rebound, or reflection from the Screen before alluded to, and the crew might be rescued by lines thrown from the top of the Screen. A vessel on the toe of a sloping breakwater would, on the contrary, be subject to the battering action of the breakers, and be further from assistance.

While the principle of the Screen would admit, as we have seen, of its adaptation to the local circumstances of wave and current—of every stage being certain of effect from being adapted to meet each necessity as it discovered itself, and of being altogether altered in position, if needs be, the nature of the structure would also render it greatly independent of faults of construction, and of the negligence of the party overlooking it. It also admits of being begun in the centre, and extended both ways until the required effect was produced.

The Screen would also possess the great advantage of continuity—that is, of oneness of character—of uninterrupted connection, with the consequent combined support of its various parts. The importance of this quality has been ably and clearly stated by Mr. Stevenson—he remarks, "It is much to be regretted that timber is so expensive in this country, and that some simple and economical specific against the worm has not been discovered for protecting Memel and the cheaper kinds of pine. The grand desideratum in harbour works, which is the want of continuity in the structure, would then be supplied. It follows, from the known laws of fluids, that each individual stone in a pier which is equally exposed throughout its whole length, is subjected to a force which it can only resist by its own inertia, and the friction due to its contact with the adjoining stones. The stability of a whole hydraulic work may therefore be perilled by the use of small stones in one part of the fabric, while it is in no way increased by the introduction of heavier stones into other parts. By the use of

long logs of timber carefully bolted together, a new element of strength is obviously obtained. A pier could be executed almost free of sea-risk, if constructed of rectangular or other shaped prisms, consisting of logs of timber treenailed and bolted together &c." The continuity here contended for would be one of the marked characteristics of the Screen.

The construction of the Screen would be simple and unattended with difficulty, either by making use of the Screen itself for the purpose, or by using a fixed staging. The capability of the fixed staging at Portland of resisting the heaviest seas, was noticed by the late Mr. Rendel: in a note to the Messrs. Stevenson, he says "it enables deposits to be carried on without interruption, almost in the heaviest weather. As an instance of this, I may remark that my Resident at Portland informs me, that the waggons and locomotives were engaged yesterday at a time when such a sea was running, that large bodies of spray were thrown 55 feet above the water-level."

The other points in favour of the Screen are omitted, to avoid the evil of overloading the subject.

Its applicability.—The Wave-Screen is capable of wide application, for there is scarcely a frontage requiring protection upon the eastern coast of England, where it could not be carried out with equal facility and advantage, but we will, by way of example, apply it for the purpose of general refuge to the single case of Hartlepool, for which place a close harbour has been projected and sanctioned by Parliament. In the writer's letter to the Hydrographer of December 6, 1856, upon the subject of a site for a refuge harbour on the north-east coast of England, and which letter appears in the appendix to the minutes of evidence taken before the Select Committee on Shipwrecks, Hartlepool Bay is described as "of a circular form, being partly enclosed by the Heugh,

a headland of soft magnesian limestone, to the northward, and by the Long Scar, a ledge of red sandstone, to the southward. It possesses, therefore, features which, if aided by properly projected works, would afford a large protected space at a comparatively small outlay." The true principle of such a work was present to the mind of the writer when giving evidence before the Select Committee on the 27th July, 1857, as the following extracts from his replies will show, viz. :—

> "It (the harbour) would be open to the sea, but not to endanger it for refuge purposes. I have mentioned my idea of a refuge-harbour to be a protected anchorage."
>
> "The exact projection (of a breakwater) would be determined upon finding out the exact set of the tide-streams, and one or two other points of information."
>
> "Speaking generally, it (the breakwater) would be curved with the direction of the tidal streams, if it could be so projected; my object being not to interfere at all with the set of the tide through, and I think that is perfectly consistent with affording all the refuge that is required."
>
> "The breakwater I have in view would protect the whole space of the bay."

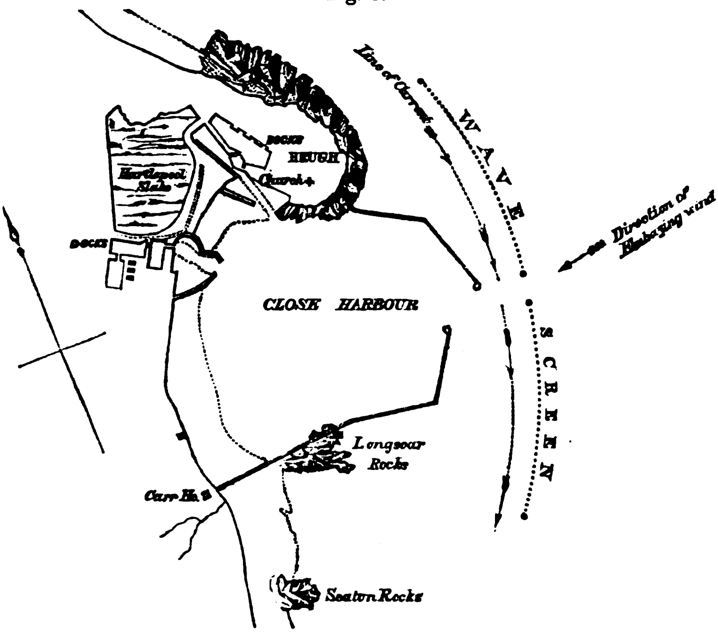
To apply the Wave-Screen to the conversion of Hartlepool Bay into a general harbour of refuge—

Fig. 5 exhibits the shore of Hartlepool bay, with the projections of the Heugh and Long Scar, before alluded to. The dotted lines represent a Wave-Screen formed in the line of the tide streams, and in a general low-water depth of 36 feet. The double lines are the piers of the close-harbour projected by the late Mr. Rendel; the outer portions of these piers are in a depth of 30 to 25 feet at low-water.

All the reasons for the formation of an open refuge-harbour and against the formation of a close one, which have already been given and we need not repeat, apply directly to the present case, and a few comparisons between the two descrip-

tions of harbour, will place their respective principles of projection in a clear light.

Fig. 5.



The close harbour would embrace a space of 470 acres with a low-water depth of 12 feet and upwards, which, at 3 acres per vessel, would afford accommodation for about 160 sail, if they were properly berthed. The refuge harbour proposed by the writer would contain 980 acres having a low-water depth of 12 feet and upwards, with accommodation for 327 sail.

The close harbour would have only one entrance, in taking which during heavy gales, vessels under small canvas, and perhaps partly disabled, would have to present their broadsides to the sea, and thus incur the risk of being thrown upon the lee-breakwater head. The Screened harbour would have three entrances, and through the central one vessels might pass directly into the body of the harbour before the wind and sea, without touching sheet or brace.

The close harbour (as stated in the writer's report upon it) would be nearly destroyed as a low-water harbour by a deposit of 5 feet, and which amount, for reasons specified, there is every reason to believe would rapidly accumulate within it. The depth of the refuge harbour would be permanent.

It is true, the close harbour would have the tranquility of a dock, but that is not required—the refuge harbour would give as much shelter in an on-shore gale as is now supplied by Bridlington bay in a northerly gale, and more than that is not wanted.

The breakwaters of the close harbour were intended to be formed of upright walls from the foundations, and to be more than 2 miles in length: it was estimated by their projector that they would cost £800,000, (not one-quarter of Sir Wm. Cubitt's estimate for works of somewhat similar character) and be eight years in building. The Wave Screen would be one and a half miles long—would cost £300,000, and might be placed in position in three years.

Such is the comparison as respects Hartlepool, and it is only necessary to add that the Wave Screen would be equally available for the protection of Blyth—the Tyne—the Wear—Whitby—Scarborough—Filey and Bridlington bays, and other frontages of like character and depth.

Duration.—Should the lower course of the Screen be formed of wood, and the upper course of cast-iron, the one would be exposed to the ravages of the worm, and the other equally subject to wastage from oxidation while unprotected by preserving coats: the duration, therefore, of such a structure, is a consideration only second in importance to its principle.

First then as respects the worm. Wood immersed in sea-water is, as is well known, exposed to the destructive attacks of various sea-animals, such as the *Teredo Navalis*—*Limnaria Terebrans &c.* The former, a species of testaceous mol-

lusk, and which is the great executioner, works within the pile, boring it in all directions—principally with the grain of the wood, and avoiding the knots. In an article in the National Cyclopædia it is said of this animal, "It now unfortunately swarms in our seas. The ravages of this apparently insignificant animal are terrible. Ships—piles—all sub-marine works, are ruinously affected by it: small as it is, it threatened the submersion of Holland by its destruction of the dykes. The rapidity of its growth, and the destructive celerity with which it works, are hardly credible." The other animal, the *Limnaria Terebrans*, is a minute crustacean—a boring shrimp. Although it does not bore deeply, it completely destroys the wood, and as the outer surface is detached, it goes deeper, so that piles of 14 inches diameter have been known to be reduced to 3 inches in 7 years. Sir S. Brown mentions that the wood piles of Trinity pier at Newhaven, of 12 to 14 inches diameter, were reduced by them to 9 or 10 inches in 6 years. It has been noticed by some observers that the primary attack of this worm is generally between low-water mark and a foot or two above it—"between wind and water," as it is called, but Mr. T. Stevenson says respecting them, "they are found to eat most rapidly between the bottom and low-water mark, but above low-water the damage is not so great; and what is singular, they do not appear to exist at all below the bottom where the pile is covered with sand. These observations do not, however, quadrate with those of Mr. Hartley at Liverpool, for he found the parts which were alternately wet and dry to decay faster than the parts which were constantly immersed. The late Mr. R. Stevenson made several experiments on the ravages of the *Limnaria Terebrans* at the Bell Rock in 1814, 1821, 1837, and 1843, by fixing pieces of different kinds of timber to the rock, and getting regular reports on their decay. From these experiments it appeared that "green-heart—beef-wood, and bullet-tree, were not attacked by the worms, while teak stood

remarkably well, although suffering at last. The kyanizing fluid and other preparations were tried, but were not found to be of permanent service." Many examples of the same sort might be given were it necessary.

The lower course of the Screen therefore, to protect it from the worm, would be formed either of wrought iron, or of those woods which are avoided by the worm, or of wood scupper-nailed, the action of the sea-water upon the nails producing a strong coating of rust. A few instances of the effectual protection afforded by this coating are very useful.

Captain Ellis, R.N., the surveyor of Southwold harbour, in a note to the writer, states, "the piles at Southwold are of Dantzic and Memel fir, and are nailed with scuppers from the ground-line, or bed of the river and sea, to about a foot below high-water mark, except in front, where the sea works most; there they are nailed to high-water mark. No nails are driven into the wood below the ground, and the drawn piles when so uncovered by scupper-nails below ground, come out perfectly sound. I believe there is nothing so effective as scupper-nailing, if the nails are carefully driven. There are now at the South pier fir piles 30 feet long by 6 inches thick, which must have been driven 40 years—they are perfectly sound above and below water, and free from the worm, and (from appearance) may last half a century yet."

Captain Smyth, R.N., of Yarmouth, also stated to the writer "we are much troubled with the worm—our piles are English or African oak—some next the river were driven in 1816—others in 1830, and those on sea face of pier in 1840. They are generally sound below low water where the nail sheathing is perfect."

Mr. James Walker, C.E., also mentioned in a note to the writer "The only wood that I have found proof against the worm is green-heart. If scupper nailing be used, fir is as good as any, the dependence being upon the iron coat of mail; not

upon the timber; and if properly nailed, the iron will preserve the timber for very many years."

Sir S. Brown in a letter to the harbour of Refuge Commissioners on the 6th of June, 1844, states "Iron nails are an effectual remedy against the attacks of the worm—it is quite clear that they never can, like cast-iron, be reduced to the state of plumbago, and that their total destruction from the effects of corrosion, would be very remote." Sir Samuel Brown's matured opinion is amply verified by the facts at Southwold, and there can be little doubt that submerged wood, so defended, would last an immense time.

The lower course of the Screen might, if necessary, be formed of pine cased in green-heart. Respecting this latter wood, Mr. T. Stevenson remarks, "no doubt green-heart might be employed so as to resist the ravages of the worm, but its high specific gravity and its great expense, would prove bars to its employment. Green-heart timber is now generally had recourse to in places where the worms are destructive. It appears to have been first used by Mr. J. Hartley of Liverpool, who published an account of its virtues in 1840, as ascertained at Liverpool docks. Its cost is considerably greater than Memel, or than most of the other timbers generally used."

The lower course might also be formed of wrought-iron cylinders. Mr. Mallet, of Dublin,—who conducted for the British Association the experiments upon iron, subjected to various conditions of wastage, and which experiments, made with the greatest care, were continued for some years,—mentions in his Second Report in 1840, that the deductions from his various experiments indicate "that from three to four-tenths of an inch in depth of cast-iron one inch thick, and about six-tenths of an inch in depth of wrought iron, will be destroyed in a century in clear sea-water, a conclusion probably not very far astray where no special perturbations or causes of corrosion supervene."

Mr. James Walker, C.E., in his report to the Trinity House, dated 24th July, 1854, in relation to the effects of salt-water upon iron, after stating many facts to assist in the formation of an opinion, sums up with this general conclusion, "That with care in selecting and afterwards protecting it, in the ways I have described, iron, whether cast or wrought, may, as respects the question of durability, be safely used in the construction of piers, or similar erections, in sea or fresh water, and its cheapness, as compared with any other metals not so subject to corrosion, is a strong argument in its favour."

The following facts bear upon this subject:—

The iron 24-pounders of the Royal George, after being 62 years submerged at Spithead, had an incrustation of oxide to the general depth of $\frac{1}{8}$ inch, below which, the metal appeared to be in its original condition.

The iron guns of the Edgar, after being 133 years under water, as well as the shot within them, were corroded to the depth of $\frac{3}{4}$ of an inch.

In the Report of the Harbour of Refuge Commissioners of 1844, it is mentioned respecting the Mary Rose, which had been 292 years under water—"The iron guns, specimens of which are in the Arsenal, are of the ancient construction, of wrought iron bars bound with hoops, and having detached chambers keyed into beds of solid wood, are corroded to the depth of $\frac{1}{4}$ inch. They appear to have been covered, and in some degree protected by the mud.

Captain Vetch stated in his Dover evidence "Some iron boats at the end of 40 years have had no perceptible decay of the iron in their bottoms, and mooring-chains taken up in Dublin bay after being 40 years immersed, have been found uninjured."

The Rev. George Abbs, of Cleadon Hall, informed the writer, that last summer the Fishermen of Whitburn, near Sunderland, recovered an anchor from the adjacent bay which

the old men of the village remembered to have been lost there sixty years ago. The crown of the anchor had been buried in the ground, a mass of which had become concreted by the oxidation of the iron, and attached to it, but all that part of the anchor which was above the ground was nearly sound, having suffered but little from wastage. It was afterwards sold for old iron.

The following (from the authority of Mr. Page, C.E., the designer of the new bridge at Westminster) are some of the structures in this country and elsewhere, in which cast or wrought iron is employed as a support, or outer casing, in rivers—viz.: Chepstow bridge—Windsor bridge—Sutton Wash bridge—Yssel and many other bridges—Yare bridge—one bridge at Chelsea—Victoria dock walls—Blackwall wharf—Rochester bridge—Liffey wharf—Wye bridge, Hereford—Shannon bridge—Wexford pier—Gravesend pier—Gravesend girder-pier—and besides these, numerous lighthouses in the most exposed situations.

The protection of malleable or cast iron from the effects of salt-water, is properly within the province of the chemist, but a fact mentioned by Mr. Mallet, shows that the isolation of immersed iron by a protecting coating, is not an impossibility. He states that Mr. Thomas Rhodes, civil engineer, whose experience in the construction of great works in iron is well known, mentioned to him that "when engaged on the locks of the Caledonian canal, certain cast-iron sluices were put down and exposed to the ocean-water, having been coated over with common Swedish tar, with the exception of their faces, which were ground together, and were removed in about four years afterwards: every part of the iron still covered with the tar was found sound and untouched as when put down; but the ground faces, which had not been tarred, were softened and converted into plumbago to the depth of $\frac{3}{4}$ inch." Mr. Mallet adds, "This interesting and important observation

shows that, if we could get any coating to adhere to the iron which would be impervious to air and water, the preservation of the metal would be effected in the best and simplest manner."

It is therefore evident from the foregoing facts, that there are no insuperable difficulties against the use of iron for the lower course of the Screen, if it were judged expedient so to employ it.

The cast-iron or wrought-iron cylinders of the upper course and the upper part of the longer stay being above water every tide, might be easily protected and rendered indestructible by the application of oil-paint, tar, or other pigment. Respecting this point, Mr. Fairbairn, in his book entitled "Useful Information for Engineers," remarks, "I am of opinion that the public has entertained very erroneous views with reference especially to oxidation, which, for the last twenty years, has been the 'rock a-head' of every iron ship. The extent of this evil has been exaggerated." Sir S. Brown says, "I think that iron which is uncovered every tide, may be preserved by the common preservative of cleansing and painting." Professor Faraday, in his letter to the Harbour of Refuge Commissioners, remarks, "In a case where coated iron-sheathing for ships was brought to me, I was much impressed by the very thorough adhesion of the coat to the iron. Hence, though iron be a body very subject to the action of sea-water, it does not seem unlikely that it might be used with advantage in marine constructions intended to be permanent, especially if the joint effects of preserving coats and voltaic protectors were applied."

Thus, while it is believed that the outside of the cylinders might be effectually defended by protecting coats, oxidation of the inside of the cylinders might also be prevented by the use of alkaline waters, or powdered lime, and as the whole work would be under constant observation, any tendency to decay might be immediately prevented—and as each section of the Screen would be independent of the rest, any portion of it

could be removed when necessary, without interfering with the stability of the structure.

Cost.—If the Wave Screen demanded an outlay equal to what would be required for a stone breakwater, it would still be the more economical work of the two, for that system is in the end assuredly the cheapest, which involves no sacrifice of the frontage intended to be protected. The structure advocated in these pages, is believed by the writer to be practicable—simple—and durable—it has also the advantage of being economical.

It has been estimated, that a Wave Screen with a lower course of pine scupper-nailed, and upper course of cast-iron cylinders, formed in a low-water depth of 36 feet, would cost as follows—viz.—with intervals between the sections equal to the diameter of the cylinders, £200,000 per sea mile—with three-quarter intervals, £225,000 per mile—and with half intervals, £250,000 per mile,—and under common circumstances it would occupy two years to construct a Wave Screen a mile long, and to form a harbour of refuge.

Sir William Cubitt, in his evidence upon Dover, stated that the average cost of the best long-slope or upright-wall breakwater formed in seven fathoms, would not be found to come much short of £1000 a-yard.* Plymouth has cost 1¼ millions at least, and is not yet completed, while Captain Washington in 1845 stated respecting that at Cherbourg, "the cost of the breakwater from 1786 up to the present time has been about two millions sterling, and it will probably require half a million more to complete it, without including the forts at the centre and the extremities. Mr. Reibell told me, that he hoped to complete it in five years—if so, its construction will have extended over a period of 66 years."

* According to a Parliamentary return, this sum appears to have been exceeded at Dover.

The difficulty and expense of constructing such harbours have, in short, been the chief impediment to forming them, and some more economical plan is loudly called for. The Wave Screen supplies such an one, based not only on intelligible principles, but is withal of so inexpensive a character, as would enable the number of refuge harbours round our seaboard to be multiplied twenty-fold.

In conclusion :

While considering the subject of Refuge harbours, the writer has endeavoured to note facts carefully, and to reflect upon them patiently, and the foregoing pages, intended as a general exposition of the opinions and views he has been led to form, may prove suggestive to others. It is trusted they will be found to contain a simple and accurate view of the subject, and that they may serve in some measure to lead the reader from a knowledge of facts to the laws by which they are governed—then to the unsatisfactory character of the present system of harbour-formation, and afterwards, step by step, to the practical lessons to be deduced from the whole.

By some readers of this pamphlet, the idea of restraining the sea, by putting, as it were, *a paling across it!* will doubtless be scouted as an absurdity, but such persons may be reminded that large effects are often the result of small causes, as witness the influence produced upon waves by oil—nets—and sea-weed, detailed in the first section. With such an overburdened repertory of patents, it is no wonder that the public view all inventions with some degree of caution, and that 'new principles,' as they are termed, are met by all the arguments that have ever been used to prove that "old things are better than new—that change is dangerous—and that things had better remain as they are."

It is evident there are two errors or extremes to be avoided in cases like the present—viz.—too great a readiness in

accepting or condemning without examination. Byron's celebrated lines should always convey a useful lesson upon this latter point—

> Thus saith the preacher : " Naught beneath the sun
> Is new ;" yet still from change to change we run ;
> What varied wonders tempt us as they pass !
> The cow-pox, tractors, galvanism, and gas,
> In turns appear, to make the vulgar stare,
> Till the swoln bubble bursts—and all is air !

Three of the *bubbles* being amongst the most important discoveries of modern times. The same amount of incredulity and ridicule fell to the lot of the inventors of the arch and the steamboat—and who can fail of being impressed by some of the incidents in the life of George Stephenson, the author of the locomotive? The leading engineers of the day were against him without exception, "yet (adds his biographer) he did not despair—he had laid hold of a great idea, and he stuck by it."

"The construction of artificial places of refuge," says Mr. T. Stevenson, "becomes a very important matter in a country where every winter's list of shipwreck and loss of life, remind us how much nature has left for art to accomplish," and he remarks, "the designing of harbours constitutes confessedly one of the most difficult branches of civil-engineering," a fact which will be endorsed by the great majority of observers. The extraordinary differences of opinion which exist among professional men upon the point, evidently constitutes it a subject upon which little is known, for though in other respects we have made remarkable progress in all things of practical moment; observation and experience, in this one instance, seem to have signally failed to enlighten us, and we are still seeking after the truth with our ideas as vague, conflicting, and unsettled as ever.

"I have," says Captain Vetch in his Dover evidence, "been

led to form a strong opinion that none of our existing modes of construction are commendable or advisable, and that if anything is to be done, we must look to new contrivances and discoveries, all of which will require to be tested by satisfactory experiments previous to adoption." The Wave Screen fulfils these conditions exactly—it is a novel contrivance; it may prove a discovery, while it is eminently susceptible of having its soundness brought to the test of experiment.

It is an argument in favour of the Wave Screen, and one well worthy of attention, that the principles of its projection were not altogether unknown to the ancients, as is apparent from the character of several of their harbours. Sir J. Rennie seemed almost to have been describing the Wave Screen, when, in allusion to the moles of Pooruoli—Porto Guilio, and Misenium, and the ports of Astium, Astia, and Ancona, he remarked, "They were all constructed on arches, and their object was to produce sufficient circulation of currents through the arches, and at the same time to have sufficient solidity to break the sea—a most ingenious and scientific principle." The ancients, in short, were careful observers, and not bad engineers—they knew what was wanted, though they failed, in this intance, to discover the exact means for securing their object.

The Wave Screen is now before the reader, claiming a careful and impartial examination alike for the cause of truth and humanity, and it is believed that the more the natural difficulties to be contended against are considered, the more it will be found that the plan is adapted to meet the circumstances, and to insure the result aimed at.

THE END.

BY THE SAME AUTHOR.

THE

CONSERVATION AND IMPROVEMENT OF TIDAL RIVERS,

CONSIDERED PRINCIPALLY WITH REFERENCE TO THEIR TIDAL AND FLUVIAL POWERS.

LONDON:

JOHN WEALE, 59, HIGH HOLBORN.

1853.

OPINIONS OF THE PRESS.

"Instances might be referred to where a course of treatment opposed to that which we have recommended has been followed by similar favourable results; but we deem it sufficient to confine this treatise to an exposition of the correct principles of river improvement, without discussing erroneous practice or its baneful results; the more so as these have been most fully and ably treated by Mr. E. K. Calver, R.N., whose investigations into the former and present state of some of our tidal rivers are of great value to the hydraulic engineer."—*D. Stevenson on* "*Canal and River Engineering.*"

"In the whole department of hydraulic engineering, there is no branch more important and more difficult than the treatment of tidal rivers. . . Upon the correct study of natural phenomena, we obtain a sure basis in nature's engineering; and we want, further, a careful collection of successful and unsuccessful application of artificial works. . . The author of the work before us, Mr. Calver, is an officer of the navy, and has been employed for many years in the hydrographic branch, and has been engaged in surveys of most of the ports between the north of Scotland and the river Thames. It is a fair criterion of the value of his services, that he has, apart from professional obligations, so applied himself to the subject of his duties as a labour of love, as to have drawn together many valuable observations, which he has here discussed for the benefit of engineers. In the exercise of his duties he has had the opportunity of studying the distinctive features of the several harbours, and he has carefully observed them."—*Civil Engineer and Architect's Journal.*

"We earnestly commend the work to all who are in any way concerned in the conservation of our commercial rivers and harbours, and of those havens which afford such invaluable shelter from the perils of our stormy and dangerous coast. And we also submit that the general reader will do well to put himself in possession both of the facts which the author records, bearing upon a subject of which no intelligent person should be altogether ignorant, and also of the scientific elucidations of those facts which he supplies."—*Mechanics' Magazine.*

"We conclude at present with an earnest recommendation of this essay to all who are interested in the Tyne, or, indeed, in any other harbour, and with expressing our conviction that in publishing this work Mr. Calver has rendered a most important service to the public."—*North and South Shields Gazette.*

"The limits of a newspaper prevents us from doing anything like justice to Mr. Calver's able and well-written treatise. . . The book is intended for general perusal; it addresses itself, it is true, to a scientific subject, but it is written so simply, and with such an entire absence of learned phrases and professional technicalities, that the general reader may derive not only instruction but gratification from its perusal. . . His modest octavo, of 100 pages, is pregnant with matter and instruction that are wanting in many ambitious productions of five times its length."—*Sunderland Herald.*

"A book on this subject by Mr. Calver is an opportune and welcome publication. If there is one man more than another entitled to speak with authority upon it, it is he, his natural abilities and great practical experience pre-eminently qualifying him to assume the office of monitor when the lesson to be taught is the right treatment of tidal rivers. We went to the study of his book with, we trust, no dogmatic determination to adhere to our own views, however much they might be at variance with those of the author; and were gratified to find that in all essential matters they are the same. . . Mr. Calver has throughout adopted a style which is sufficiently technical for practical purposes, whilst it is perfectly intelligible to ordinary readers. It presents, in an agreeable form, an important study for all who take a scientific interest in the laws of hydraulic motion, or are commercially concerned in the proper maintenance of our tidal rivers; and no member of a river commission or dock directory should be without a copy of it."—*Sunderland News.*

"This little volume, though of modest pretensions, has matter which will afford serious grounds for consideration among both professional and non-professional readers. . . Mr. Calver is well qualified by his previous experience for the task he has undertaken. . . He has the further advantage, from the position he occupies, of being removed from the bias of local interests, and the conflict of rival claims, and added to this, the experience of a life devoted to watching the operations of nature, gives him an opportunity of forming an accurate, as well as an impartial judgment on the subject of which he treats. His book is therefore entitled to be received as the abstract of the experience he has acquired in the public service, with the deductions of a dispassionate, and, we may add, from the testimony of the book itself, a close, able, and intelligent observer."—*Newcastle Chronicle.*